METALLURGIA

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Caught Sub.

IT always seems less than justice that the identity of the member of the ground staff who stands in for an injured player, when his side takes the field, should be shrouded in a mist of anonymity when he takes a catch. Perhaps it is considered that the introduction of his name into the records would cause confusion. On the other hand, it may be felt that his name should not appear because he was not one of those originally chosen—a kind of inferior being and unworthy to be numbered with the elect. Maybe his batting and bowling would show certain shortcomings, but there can be no denying that his fielding at that particular moment was adequate. One can recall, too, the brilliant performer with bat or ball who is a constant source of worry to the captain in his efforts to find a suitable " hiding place " where his inadequacy as a fieldsman will matter least. It is all a matter of fitness for the job in hand.

The dictionary definition of substitute—" one who, or that which is put in place of another "—contains no reference, direct or implied, to inferiority or superiority. In point of fact, the same dictionary defines substitution in algebra as " replacing one quantity by another which is equal to it but differently expressed." Nevertheless, the term has of recent years acquired this inference of inferiority—possibly in consequence of its wartime associations. Before the war we used to smile indulgently at the thought of Hitler's Reich eating " ersatz " food, drinking " ersatz " coffee, and even working with " ersatz " materials. When war came, we were soon to discover that Germany had no monopoly of substitution, and so we came to have margarine as a substitute for butter, dried egg in place of shell eggs, and whalemeat in place of steak.

Not only in the case of food was substitution found to be necessary—scarcity of raw materials had its effect on materials of construction too, and many were the changes wrought in once familiar materials, as first one metal and then another became scarce. Here, again, certain cases gave support to this idea of inferiority. For instance, although the high-speed steels in which much of the tungsten was replaced by molybdenum had quite good properties, they had one serious drawback for certain applications—excessive surface oxidation occurred on heat-treatment. It should not, of course, be thought that all " substitutes " had a transient existence, as is evidenced by the aluminium casting alloy D.T.D. 424 which was developed to make use of the high copper content Duralumin scrap from aircraft factories. This alloy is now used in practically every light alloy foundry in the country for castings which are only lightly stressed, although, as is emphasized in a paper presented to the Annual Conference of the Institute of British Foundrymen last month, it is actually capable of giving much greater service in the engineering field.

Now, after a period of relative easement, first dollar shortages and then rearmament requirements have brought forward, once more, the need for economy in the use of certain strategic materials. These two aspects of the same problem are, of course, quite different in their effect on raw material shortages. Where materials are scarce because of the need to conserve dollars, the shortage can easily be overcome if the need is proved, as in cases where it can be shown that the dollar return from completed exports will show a handsome margin over the dollar expenditure on raw materials.

The rearmament programme results in an altogether different situation. Certain materials will no doubt be required for defence purposes in large quantities—in fact an appreciable proportion of world production—so that such materials will no longer be available for less essential uses, whether service or civilian. Then the question of substitution is an absolute necessity. Fortunately a certain amount of experience was gained in World War II, and although details of schemes capable of meeting the present situation may differ, due to the altered raw material position and the shift in emphasis on the requirements for individual metals, the schedule previously adopted will nevertheless form a useful guide to those responsible for effecting economy.

This revival of the strategic materials problem raises issues far beyond the present limited considerations. As Professor Murphy said, in his Presidential Address to the Institute of Metals earlier this year, " The use of a higher grade of metal than the application, or the method of manufacture, technically demands, or the unnecessary use of one metal in place of another more freely available, and likely to remain so, is metallurgically inefficient." In the present circumstances, it behoves all concerned to give serious consideration to the materials they use, with a view to conserving scarce elements. There must be many cases where materials with somewhat lower properties could replace those in use. In many cases a material would commend itself to the designer because of its excellent properties, and subsequent freedom from failure was, no doubt, taken as an endorsement of the choice. But that doesn't prove that a material with slightly lower properties would have failed. There is obviously no point in taking unnecessary risks, but consideration might be given to a re-minted wartime phrase—" Is your alloy really necessary."

We referred earlier to the anonymity of substitutes in cricket. It is most essential, in substitution of materials, that as much information as possible should be available on all aspects of the substitute, particularly where substitution is allowed as a relaxation of a standard specification. It should be remembered that the material may have to withstand various processes, and any precautions necessary, as, for example, in welding, should be brought to the notice of all concerned. In this way troubles of the type experienced in World War II, when a material with equivalent mechanical properties replaced another with greatly superior weldability, may be avoided.

Personal News

DR. C. SYKES, F.R.S. has been appointed Managing Director of Thos. Firth & John Brown, Ltd. Dr. Sykes became Director of Research at the Brown-Firth Research Laboratories in 1944 and was elected to the Board of Thos. Firth & John Brown, Ltd. shortly afterwards. He succeeds SIR ARTHUR MATTHEWS who has retired after 29 years service with the Company. Sir Arthur remains a Director of the John Brown Group of Companies.

MR. D. A. OLIVER, Director of Research to the B.S.A. Group of Companies, has been appointed part-time Metals Economy Adviser to the Ministry of Supply.

MR. FRANCIS B. RICHARDS has retired from the Chairmanship of Woodall-Duckham, Ltd., the holding company of the Woodall-Duckham Group. At the request of the Directors he has retained a seat on the Board. He is succeeded by MR. T. CAMPBELL FINLAYSON who is also Chairman of the Woodall-Duckham Vertical Retort & Oven Construction Co. (1920) Ltd., the principal operating company of the Woodall-Duckham Group.

THE Iron & Steel Corporation of Great Britain announce the following changes in the Boards of three publicly owned companies.

The Kettering Iron & Coal Co., Ltd., Kettering

MR. F. SCOPES has been appointed Director and Chairman in succession to MR. JAMES GOUGH, who recently resigned.

The New Cransley Iron & Steel Co., Ltd., Kettering

MR. H. J. ELLISON, Chairman and Managing Director has retired; MR. F. SCOPES has been appointed Chairman, and MR. G. H. JOHNSON Managing Director.

Mr. Scopes is Managing Director of the Stanton Ironworks Co., Ltd. His appointment to the Chairmanship of the Kettering and New Cransley Companies does not imply any connection between the Stanton and the Kettering and New Cransley Companies. Mr. Johnson is Managing Director of the Kettering Iron & Coal Co.

Glynhir Tin Plate Co., Ltd., Pontardulais, Glamorgan

MR. EDWARD WITHINGTON and MR. N. W. FISCHER have retired from the Board. MR. W. S. G. REES has been appointed Chairman and MR. O. J. THOMAS, MR. IVOR LEWIS, and MR. E. ARTHUR WITHINGTON have been appointed Directors.

THE British Welding Research Association announces the following staff changes:—

NICOL GROSS, Ph.D.(Cantab), A.M.I.Mech.E., Mem. A.S.M.E., has been appointed Assistant Director of Research. Dr. Gross will continue his responsibility for the Association's engineering researches and will remain in charge of the Research Station at Abington.

K. WINTERTON, Ph.D., B.Sc., and H. E. DIXON, M.Sc., A.I.M. have been appointed Chief Metallurgists, the former for ferrous metals, and the latter for non-ferrous metals.

C. L. M. COTTRELL, M.Sc. and P. T. HOULDCROFT, B.Sc. have been appointed Assistant Chief Metallurgists for ferrous and non-ferrous metals respectively.

DR. EGON OROWAN has been appointed George Westinghouse Professor of Mechanical Engineering at the Massachusetts Institute of Technology. Dr. Orowan joined the faculty of the Institute last June, and he now succeeds Professor William R. Hawthorne, who has held the Westinghouse chair since 1948. Professor Hawthorne is resigning to accept the post of the Hopkinson and Imperial Chemical Industries Professorship of Applied Thermodynamics at Cambridge University.

DR. D. B. FOSTER, M.I.Mech.E.,F.Inst.F.,A.M.I.Chem.E. has joined Mullard Ltd. as Chief Engineer of the Equipment Division. He has also been appointed Executive Director of Mullard Equipment, Ltd., the subsidiary company which manufactures scientific and telecommunication equipment.

DR. N. C. ROBERTSON has been appointed Director of the Petrochemical Research Department of National Research Corporation, Cambridge, Massachusetts.

Pressed Metal Industry

American Team's Reciprocal Visit

THE second of the Productivity Teams from America to pay a reciprocal visit to the United Kingdom arrived at the end of June. Drawn from all levels, it is representative of the American Pressed Metal Industry and its visit comes as a sequel to that of the British Pressed Metal Productivity Team to the United States in 1949. The object is further to discuss mutual problems with the British industry.

During the tour opportunity will be afforded to examine in detail the British Team's recommendations in relation to current problems and to appraise recent developments in the industry in this country. Visits have accordingly been arranged to a number of leading British establishments engaged in various types of metal pressing.

Prices for Secondary Aluminium Alloys

FOLLOWING the introduction of the Aluminium Scrap Prices Order, 1951, and in the absence of a similar Order controlling the prices of secondary aluminium and aluminium alloy ingots, the members of the Federation of Secondary Light Metal Smelters recently adopted a range of maximum selling prices for their products.

The maximum prices adopted on April 9th, 1951 were based on the prices of raw materials and production costs at that time, and the Federation announces that, as a consequence of the increases in the prices of silicon metal and copper, its members find it necessary to increase the maximum selling prices of the undermentioned alloys for deliveries on and after July 2nd, 1951, as follows:—

L.M.1	from	£128	per ton to	£129	per ton
L.M.2	,,	£145	,,	£148	,,
L.M.4	,,	£132	,,	£133	,,
L.M.6	,,	£155	,,	£159	,,

Graduate Course in Metallurgy

THE Graduate Course in Metallurgy in the Industrial Metallurgy Department of the University of Birmingham is part of a national scheme to maintain a supply of men fitted for technical positions of major responsibility in industry. It provides a year's training in industrial metallurgy at a post-graduate level for men who hold degrees in metallurgy, physics, chemistry or engineering and who are already engaged in, or proposing to enter, metallurgical industry.

The inclusive fee for the Graduate Course in Metallurgy is £70. The course begins on October 1st, 1951. Further details and forms of application may be obtained from the Registrar, The University, Edgbaston, Birmingham, 15.

The Properties of Materials and the Engineering Uses of Cast Metals

By R. W. Bailey, D.Sc.(Eng.), Wh.Sc., M.I.Mech.E., F.R.S.

A slightly abridged version of the Edward Williams Lecture delivered on June 13th, 1951, at the Annual Conference of the Institute of British Foundrymen held at Newcastle-on-Tyne.

THE choice of a material for any purpose whatever must, of course, be dependent in some measure upon the material's properties, including cost as a property, but for engineering uses the term properties has generally a restricted range, and usually refers to such qualities as strength, elasticity, ductility, ability to withstand repeated loading and shock, which would ensure reliability under operating conditions of loading and temperature. In addition, there are such physical properties as density, thermal expansion, thermal conductivity, electrical resistance and magnetic properties, any one of which may be of high, and, in some circumstances, of dominating importance, in specific cases. Even this restricted range of properties is clearly still a large one, but since most engineering structures have to be designed to transmit loads, strength would generally be given priority in importance, with ductility as a partner, but one of quite uncertain significance concerning the overruling requirement of reliability, and one which, in my view, is frequently over-valued as a property, as distinct from the indication it may give of an abnormal and unsatisfactory condition. In view of the importance attached by engineers to strength and ductility, attention is given first to these properties.

Strength and Ductility

Great importance is attached to strength (usually tensile strength is understood, since strength in compression would always be greater than in tension) because, more than any other property, it determines the cross-sectional area of a part, whether the loading is static or variable. This is so when it is variable because the fatigue resistance bears a ratio to the tensile strength, termed the endurance ratio, which is 0·4–0·5 for a wide range of metals. It is unusual, however, to base design directly upon fatigue test data, since failure in practice depends so much upon other factors, such as the character of the disturbing forces, effects of notches and surface condition, etc. Experience with a particular kind of part in service is, therefore, of much greater importance in determining the permissible nominal variable stress; consequently, strength remains the dominant property.

Despite the information yielded by failures of parts in service, where frequently ductility has clearly played little or no part, most engineers have a feeling that ductility confers greater security. Therefore, before considering engineering possibilities of cast metals from the standpoint of strength, it will be as well to enquire what measure of assured ductility is really useful in practice.

That the essential ductility must be quite small, for most engineering uses, is evident if one considers the case of hardened gears in, say, motor vehicles, which are subject to high loading of a repeated kind and heavy shocks at times, with stress concentration present, and where a tensile test would show not more than 1% extension, including the elastic strain, which would constitute the greater part. A virtue assigned to ductility, or plastic strain, is that it accommodates stress concentrations and thus prevents the high stress values which would occur without plastic strain. But a stress of say 40 tons/sq. in. and a stress concentration factor of 3, bringing the unrelieved stress to 120 tons/sq. in., could have the difference between, say, 80 and 120 tons/sq. in. accommodated by an extension of $(40 \div 13{,}500) \times 100$, or by slightly under 0·3%. It will be clear from this example that an assured ductility of 1% extension is likely to be adequate for safety in most engineering uses, but of course commonly more would be welcome, and would be essential in special cases such as lifting chains and gear. However, there is a considerable difference between small essential magnitudes, and those generally specified for wrought materials, which understandably tend to create a scale in the minds of engineers when considering castings.

Castings or Forgings

Leaving out brass and bronze castings, which were often chosen for other properties than strength, the serious entry of castings as an alternative to wrought parts occurred with the production of steel castings, where the choice was between the same, or very similar, materials, in the cast and wrought forms. In this connection the question naturally arises, what is the influence of forging? The answer from experience is, that given clean and sound material there is frequently little or no influence. The improvement often found with forging arises from its action in rendering a defective condition less harmful, though the condition may be in nowise an abnormal or remediable one. This may be exemplified by the case of a large rotor forging, where the reduction by forging on the body is 2·5 : 1 (on cross-sectional area) and at each shaft end 20 : 1. The physical properties obtained by tensile testing, are given in Table I, the test piece positions being shown in Fig. 1. It will be seen that the properties at the axial position in the body, and in the shaft end, are equally good for the

TABLE 1.—PHYSICAL TEST FIGURES FOR A TURBO-ALTERNATOR ROTOR.

Test Piece	Ultimate Tensile Strength tons/sq.in.	Yield Point tons/sq.in.	Elongation %	Reduction of Area %
TL.	45·6	25·5	23·0	39·2
TR.	45·0	25·0	17·0	30·6
TX.	45·8	26·0	18·0	24·6
BL.	42·5	24·0	23·0	41·9
TC.	47·5	25·5	18·0	36·4
MC.	47·8	26·0	8·0	10·0
MC2.	41·5	23·5	6·0	11·7
BC.	39·6	21·5	28·0	41·9

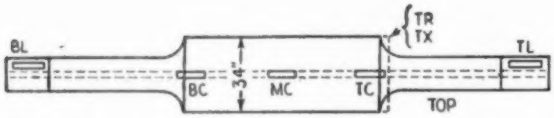


Fig. 1.—Rotor forging showing test positions. See Table I for test results.

end near the bottom of the original ingot. That a steel casting can give the properties of a high-class forging when the metal is clean, and segregation is negligible, is shown by the results of tests upon a large flywheel, cast in the usual sand mould. In Table II the results of tests taken at positions indicated in Fig. 2 are given.

TABLE II.—PHYSICAL TEST FIGURES FOR A HIGH QUALITY CAST STEEL FLYWHEEL.

Test Piece	Ultimate Tensile Strength tons/sq.in.	Yield Point tons/sq.in.	Elongation %	Reduction of Area %	Bend Test
A	37	22	27	45	180° unbroken
B	36·5	22	27	46	180° unbroken
C	37	22	25	36·4	180° unbroken
D	36·5	22	29	48·8	180° unbroken
E	37	23	27	50	60° broken
F	37	23	26·5	50	180° unbroken
G	37·25	23	28	50	180° unbroken
H	37	22	17·5	30·8	180° unbroken

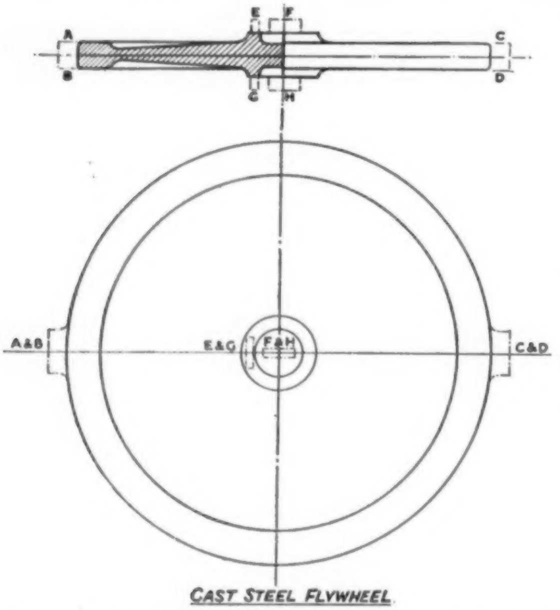


Fig. 2.—Cast steel flywheel, 12 ft. dia. See Table II for test results.

Experience in both cases shows that ductility is reduced by segregation, and that in the case of a forging, ductility may be improved by a sufficient reduction by forging.

As an example of a high-duty non-ferrous casting, a high-tensile manganese-aluminium-brass retaining ring for a single-phase turbo-alternator may be cited. The chemical composition and tensile properties of the ring were as follows :—

	Cu %	Zn %	Fe %	Mn %	Al %
Composition	6[illegible]·4	26·5	1·5	1·8	5·3

	Y.P. tons/sq. in.	U.T.S. tons/sq. in.	Elong. % 4=A	R.A. %
Physical Properties	32·8	44·5	9	13

Such rings have now been superseded by non-magnetic steel forgings, warm worked to a tensile strength of 60 tons/sq. in. The few cases of failure in service of these non-ferrous castings were not due to any casting defects, but to intergranular cracking, of the "season cracking" type, the most serious in the lecturer's experience having been traced to the presence of ammonia in the atmosphere at the power station concerned, due to the proximity of a manure and fertiliser works.

These examples will suffice to show that engineers have confidence in castings operating under severe conditions, provided the material has the requisite strength, cleanliness and assured ductility.

Elevated Temperature Properties

So far, working temperature has not been mentioned, and as tests are commonly made at atmospheric temperature, it is usual to think of material properties at this temperature. There is, of course, a considerable field of usefulness for castings at elevated, and, indeed, quite high, temperatures, where, if they possess the necessary strength and reliability, they may not only offer an alternative to wrought material, but in some cases they may be constructionally and economically superior. The ability of metals to withstand loading in service at elevated temperatures is dependent upon the extent to which they undergo permanent deformation or creep, under load, and a very extensive field of special testing, as you will know, has come into existence during the last 30 years to determine the behaviour of metals in this respect. The phenomenon is not in itself very new, and foundrymen have long been aware of one aspect of it in the distortion of castings and the use of a seasoning period or treatment to minimize its ill effects. Indeed one of the great early pioneers in testing the properties of cast iron, E. Hodgkinson, who was responsible, as you will know, for a well-known formula for the strength of cast iron columns, and who also settled the cross-section proportions of cast-iron beams, must have been one of the first, perhaps the very first, to make creep tests. He measured the progressive shortening of a series of cast-iron columns under different loads, and their life to failure ; the results of his tests were reported in the year 1840[1]. Now vast numbers of tensile creep-testing machines are in use and are being added to all over the world, to meet high-temperature needs, but they are mainly applied to the testing of steels and heat-resisting alloys. Nevertheless Hodgkinson's work on Cast Iron Pillars is historic and I would quote his words : "In all the previous experiments, the pillars were broken without any regard to time, and an experiment seldom lasted longer than one to three hours. There might, therefore, be considerable doubt upon the minds of many persons whether the results obtained would be consistent with those which would arise from long continued pressure. At my suggestion, therefore, Mr. Fairbairn had the apparatus erected, by which pillars might be permanently loaded."

Two circumstances in our times which should have created a rational perspective regarding the significance of strength, microstructure and ductility of cast vis-a-vis wrought metals, are the behaviour of metals at elevated temperatures, and the advent and wide use of electric

1 Hodgkinson, E. "Experimental Researches into the Strength of Pillars of Cast Iron, and other Materials." *Phil. Trans. Royal Society*, 1840.

arc welding. Both these developments violate earlier ideas of what appeared desirable, and what should be approved or disapproved. Together they provide a reasonable background against which properties and the engineering uses of cast metals may rationally be judged. Let us first notice the behaviour of metals at elevated temperatures.

At temperatures where creep operates, short-time tensile tests may show good strength with unimpaired ductility at fracture, but at lower stresses, failure in a long time may occur at much reduced ductility. This is particularly so in the case of materials of high resistance to creep, which would therefore be chosen for parts employed for strength at high temperatures. Low ductility in this case results from intercrystalline cracking which supervenes before large deformation has developed. Commonly the long-time ductility of the material used for high-temperature plant would not be more than a few per cent. extension. Safety against failure has to be provided by the margin this ductility has over that which takes place, and which by design is limited by the working stress. Thus, wrought materials possessing high ductility, as shown by the usual short-time tests, may really operate under conditions causing the ductility at failure to be low, and the normal ductility by short-time test to have little or no practical significance when operation is considered. The position of cast metals for high-temperature service should therefore be judged from this more favourable standpoint.

A corresponding modification of views is to be expected from the widespread adoption of welded structures. Electric arc welding has brought with it a wide range of microstructures and often residual stresses which have now to be accepted, although many metallurgists of, say, two decades or so ago would have been greatly disturbed by their presence in structures of wrought materials. This must have compelled the conclusion in practical minds that microstructure, provided it does not reveal a dangerous feature, is in many cases of small importance in itself, and that it is upon effective physical properties that the suitability of a metal part rationally depends, and it should be judged upon this basis. Hence the great importance of properties of materials in assessing engineering uses of cast metals.

Fatigue

An outstanding example showing a full appreciation of the importance of material properties in influencing the engineering use of a cast metal, is furnished by the work done to improve the strength and ductility of cast iron, and particularly in investigating the use of cast iron for crankshafts of internal combustion engines. Members of this Institute will be closely familiar with this important work through the valuable contributions made by the British Cast Iron Research Association; through papers contributed to your Institute; to a less extent, perhaps, through the admirable work carried on by the Motor Industries Research Association; and, lastly, through your own direct experience. But this work must also have important lessons for engineers, because of its general usefulness in throwing light upon what properties are essential and what are inessential to security.

Crankshafts have rightly been regarded as a most vital component of engines, subject as they are to high loading of a repeated or cyclical character, producing torsional and bending stresses, associated frequently with forced and sometimes synchronous vibration of both kinds. The essential form of the part involves regions of high local stress which can only be mitigated, but not removed, by skilful design and generous fillets, and good resistance to wear at journals is important. Material properties of a high order, such as strength, ductility, surface hardness, notch bar value, notch insensitivity and fatigue resistance were looked for in forged steel shafts, and by many engineers they were regarded as essential. But clearly the successful operation of cast-iron crankshafts has assisted in creating a more reliable perspective regarding the significance of these properties, and this has been made more precise by the extensive investigation of the materials used.

Next to strength and ductility, or, more widely, the ability of a material to deform safely in service, the ability of a *part* to withstand repeated, fluctuating, and reversing stresses is a property of great practical value. It is embraced generally by the term fatigue, and a vast amount of fatigue testing of metals has been carried out over the years, of which only a small part can be said to have had much influence upon the choice and use of materials. This is because test pieces are frequently not strictly representative of actual parts in material, surface condition and scale, but are employed to measure or investigate a material property which has usefulness for comparative purposes. This property is rarely a basic factor in design, although it may influence practice in manufacture, as for example the use of a surface treatment to increase resistance to fatigue failure. Parts should not normally fail by fatigue, but they do at times, and most frequently the cause is stress arising from vibration at a critical or natural frequency, faulty design producing high-stress concentration, or the presence of a defect, or defective surface condition—a case may be cited where fatigue failure of a steel shaft resulted from an electric welder touching the shaft with his live electrode. Change in design is usually the only satisfactory remedy, and as this is generally possible, it is the course commonly followed. Almost always a material is chosen for some property other than its specific resistance to fatigue.

In connection with fatigue, the subject of the internal damping capacity of a material or its property of absorbing energy—as by internal friction—under cyclic stress, is continually cropping up. Damping capacity has considerable scientific interest and value in the physics of metals, but because its amount is usually small compared with that contributed by constructional and operational features of machines and machine parts, it has very little influence in engineering practice, and none in my experience in determining the choice of a material for a particular part.

It should not be assumed from our remarks upon the fatigue resistance of a material, that fatigue is a property of little importance. Fatigue testing becomes of very considerable practical importance when it is applied to actual parts, and, therefore, when it makes an approach to the conditions which occur in engineering practice. Here the factors of material, surface condition, design, and perhaps the character of the loading are present and the test becomes an endurance test under the special conditions determined by these factors, in association. Strain gauge technique may in some cases be utilised to enable actual stresses to be measured, but usually the

intensity of the loading can be represented by a nominal calculated stress, which can be utilised for design.

Applied Strain Fatigue Testing

An extremely useful type of fatigue testing machine is one in which a movement of controllable amount can be imposed upon the part under test, to determine the loading. A valuable feature of the type is that it imposes a specific strain, as distinct from a specific load or stress. Frequently such machines are simple and readily constructed. A good example of this type of machine has been applied by the Motor Industry Research Association[2] for investigating cast-iron crankshafts. Fig. 3 illustrates the equipment and shows a single throw crank of standard form used for the tests, which is tested stationary in the position shown. The crankshaft at the remote side of the crank is held firmly by a clamp, and at the near side has an extension whose end is displaced up and down, thus subjecting the crank webs and pin to bending. The movement is applied by the vertical rod shown, being derived from an adjustable eccentric mounted on the driving shaft below the crankshaft. By means of loading by weights, and the measurement of strain at some position of the part, calibration can be effected. Fig. 4 shows a battery of six cantilever mechanically operated repeated strain testing units, employed by the lecturer's company, where the displacement and loading applied by each machine is derived from an eccentric of fixed eccentricity, and the load and displacement are varied by altering the length and flexibility of the cantilever, and thereby the strain and bending moment it transmits to the part or material under test is determined.

We have made reference to the applied strain type of machine because cast materials can often best be judged in comparison with wrought metal for engineering parts by tests of this kind when fatigue or repeated strain is the criterion. This is because, frequently, failure, if it occurs, will take place where there is a gradient of stress and strain, as at a fillet or hole, and the strain which may lead to failure is likely to be partly plastic and partly elastic, and the accompanying stress will be determined by the stress-strain characteristics of the material, which will be different with different materials. A shaft rotating in three bearings with a specific misalignment would be a case of applied strain.

Many parts which appear to fail by fatigue, do so not under millions of applications of stress, as in the common fatigue test, but under a comparatively small number of applications of excessive strain. It is the large pot holes and heavy bumps which most damage a road vehicle spring. The ordinary fatigue test and fatigue test results throw little useful light upon the important property of a material to withstand repeated heavy strain without developing a crack. This property is best investigated by the applied strain type of machine. A cast material having good behaviour in this respect would have substantial claims for use as an engineering material. A measure of ductility is clearly needed, but it should be ductility which allows a large number of cycles of strain to be withstood safely—a descriptive but inelegant word for this property would be "concertina" ductility.

2 Motor Industry Research Association Report No. 1950/2. "Fatigue Strength of Cast Crankshafts: First Report on the Influence of the Crankshaft Material on Bending Fatigue Strength," by R. J. Love.

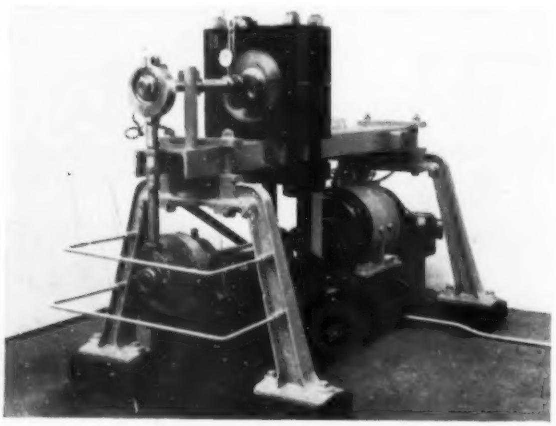


Fig. 3.—Fatigue testing machine for testing crank webs and crank pins in bending. Motor Industry Research Association.

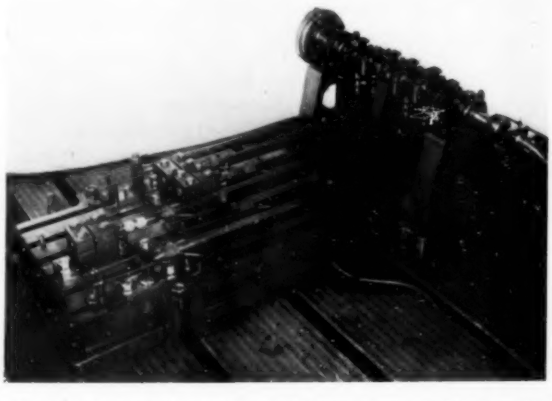
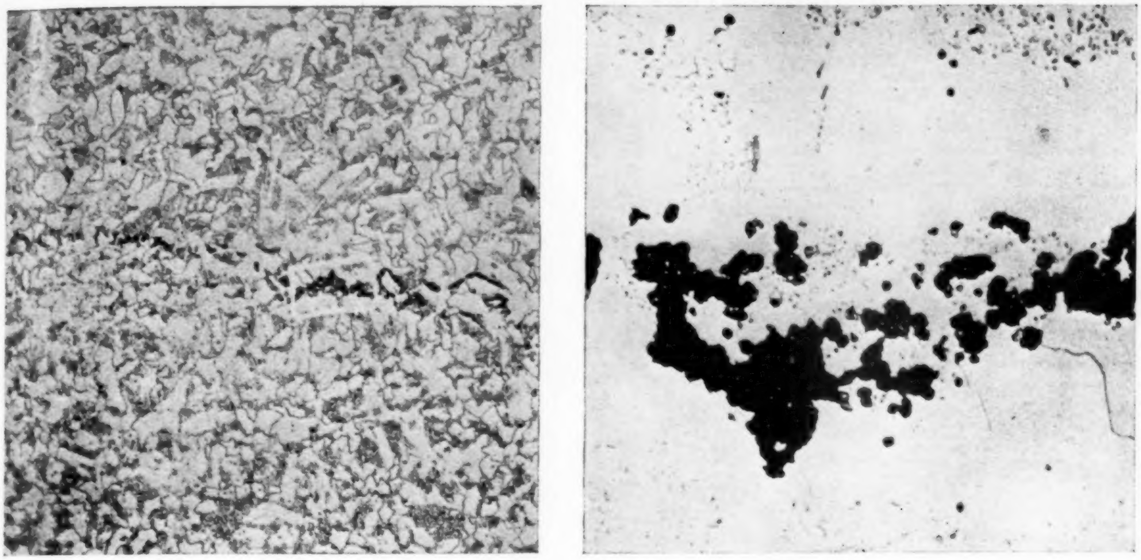


Fig. 4.—Repeated strain cantilever type fatigue testing machine. Metropolitan-Vickers Electrical Co., Ltd.

Improved Cast Irons

The recent improvements of cast irons resulting in a measure of ductility and much improved strength, notably by causing the graphite to be spheroidal, may also have conferred the property of withstanding repeated high strain. If so this would be an important gain and would increase the engineering value of the material.

Another direction in which one may expect cast iron having spheroidal graphite to offer interesting possibilities is in applications to parts operating under stress at high temperatures as in steam power plant. Hitherto the use of flake-graphite cast iron has been restricted in steam power plant to medium temperatures, rarely over 350° C. (662° F.), even for the most satisfactory compositions, because of growth trouble experienced some years ago. This should be very greatly reduced by the new irons, and this has already been contemplated. If growth does not become of significance at temperatures of 450°–550° C. (842°–1,022° F.), where the material would be subject to creep, important further possibilities are open to it for investigation and application in high-temperature plant.



× 100 × 1,000

Fig. 5.—" Chain " graphite at heat affected zone of electrically welded steam pipe.

Engineers have lived so long with stress and strain dominated by elastic theory, that vision may be handicapped by the limitations this theory imposes, and which in fact may largely be removed by plastic strain effects occurring as creep at high temperatures. One of these limitations is stress concentration. It is well known that a hole in a plate, small compared with its width, when the plate is under tension results in tensile stress at the sides of the hole three times the mean stress in the plate. This at first thoughts might raise doubts about the influence of the roughly spherical cavities in spheroidal graphite cast iron. However, creep would substantially remove the tensile stress concentration, and in my view it is probable that cracking, which would be intergranular and determined by tensile stress, would not be appreciably hastened by the small graphite filled cavities. Indeed, as cracking of creep test specimens seems always to be initiated at the surface, and, we believe, involves to some extent an effect of the atmosphere, it is possible that the graphite might operate advantageously. At any rate, investigation by creep tests would provide the answer, and it should be undertaken—perhaps interested individuals are doing this or may have done so. However this may be, operating temperatures have now reached a level such that the long operating life expected of steam power plant has made graphitisation of wrought steels a possibility, and apparently a certainty at the heat affected zone of an electric weld.

The sudden failure in an American power station of an electrically welded steam pipe[3], due to graphitisation, directed a great deal of attention there to the possibility of this phenomenon occurring in service, especially as operating temperatures have continued to increase. The use in steelmaking, in the United States, of substantial amounts of aluminium for deoxidation was a predisposing cause not present in British practice, and although this has now been corrected in steam pipe manufacture, there is no doubt that with the higher operating temperatures coming into use, graphitisation must be regarded as a possibility. Experience in America has shown that at the heat affected zone of an electric weld graphitisation may take two forms, a dangerous one descriptively referred to as " eyebrow " or chain graphite[4] (Fig. 5), and the common normal granular or random form which may occur in parts not influenced by welding, the presence of which is not regarded as serious in itself. If this is a correct assessment, the graphite form in spheroidal graphite cast iron, because of its rounded character, should be even less of a risk. One may expect, however, that as a steel may graphitise because of its long life at a high operating temperature, a cast iron having spheroidal graphite as cast, because of the great activity in promoting diffusion of carbon conferred by the accelerating element used, e.g., cerium or magnesium, would undergo considerable changes as a result of similar operating conditions, and it would be a matter for investigation to determine what these changes might be, and their effect upon physical properties.

It is a circumstance of considerable interest that the development of wrought ferritic steels for high-temperature service, and the improvement of cast irons stimulated by the need for improved tensile strength and ductility, should have resulted in materials which under advanced operating conditions promise comparable ductility, may be graphitic, and may not be widely different in their physical properties at operating temperature. There seems to be good grounds for hope from recent developments that the range of usefulness of cast iron for high-temperature steam plant may be increased. This would no doubt be welcomed by iron foundries already producing castings for the lower range of temperatures.

3 " Symposium on Graphitisation of Steel Piping." A.S.M.E. Annual Meeting, New York, N.Y. December, 1944.

4 Hopping, E. L. and White, A. E., " Report on Graphitisation Studies on High-Temperature Welded Piping of the Philadelphia Electric Company." A.S.M.E. Annual Meeting, New York, N.Y. December, 1946.

"Lost-Wax" Casting

For very high operating temperatures which gas turbine development has necessitated, it is recognised that superior alloys may be impracticable in wrought form, or may present production difficulties which would be avoided by castings, and it is because of this possibility, that particular interest has been taken in the "lost-wax" process of precision casting, and it accounts largely for its most common application to the production of gas turbine blades. Cast blades have proved satisfactory for the stationary guide vanes, but the need has not yet arisen for their use as moving blades, where the operating stress is more severe. Experience has shown that stationary blades of jet aircraft gas turbines are liable to cracking as a result of unequal heating at combustion hot spots, particularly when starting, and that the character of the cracking is usually intergranular. Materials are tested for resistance to this tendency, and in this property cast materials show good performance.

Either by inference, or directly, I have endeavoured in this lecture to convey the view that for engineering uses castings, where they may offer an alternative to wrought metals, have as wide a field of use as their physical properties justify, and their competitive position allows. Given high quality, both in materials and product, castings in most cases need not be at a disadvantage in physical properties compared with wrought metals. In any case, their promise and prospects for engineering uses, apart from considerations of cost, may be assessed upon the results of mechanical tests and metallurgical examination interpreted with intelligence. Within the limits of the time available, I have endeavoured to convey my view point in this respect through the subjects discussed. Upon this basis I look forward to an extension of the use of cast metals in engineering application, commensurate with their material properties of essential character.

Acknowledgments

The lecturer acknowledges his indebtedness to the Directors of Metropolitan-Vickers Electrical Co., Ltd., in particular to Sir Arthur P. M. Fleming, C.B.E., D.Eng., Director of Research and Education, for permission and facilities in preparing this lecture, and to Mr. A. Fogg, M.Sc., M.I.Mech.E., Director of the Motor Industry Research Association for access to the Association's Report No. 1950/2 and the use of Fig. 3.

Bristol Industries Exhibition
Imperial Smelting Stand

To those who are inclined to think only of the Imperial Smelting Corporation as a manufacturer of the raw material used as a basis for zinc-base die castings, for galvanising, and for alloying with copper to make brass, a visit to the Bristol Industries Exhibition, held recently on the Corporation's sports ground at Stoke Bishop, would be both interesting and instructive, for the display on the I.S.C. stand portrayed not only the production of zinc and its uses, but also the production and uses of its ancillary products.

An introduction to the stand presented a brief history of zinc, noting its close connection with Bristol, where William Champion, as early as 1740, had established a works "for extracting the metal from calamine." For many years practically the whole of the world output of zinc was produced in horizontal retorts, but recently, the vertical retort process, first developed by the New Jersey Zinc Company, has come into use in countries where labour is expensive, as although the plant is more costly, less labour is required for operation. Both processes are employed at Avonmouth and the vertical retort process was strikingly depicted by means of the "working drawings" and photographs seen in the background of our illustration.

A further panel display showed the stages through which sulphur dioxide (a by-product of the roasting of zinc blende to convert it into oxide) must pass before it is finally converted to sulphuric acid, the shortage of which has been responsible for much concern recently. A vital basic material for industry, a few of its uses, selected to indicate its wide sphere of application, were shown photographically. Amongst them is the production of chemicals containing fluorine, a development which the Corporation pioneered in the United Kingdom. Since the installation, a few years ago, of a unit for the production of anhydrous hydrofluoric acid, the field has been further explored and the Corporation is now in a position to supply elemental fluorine, polyfluorides of certain metals such as cobalt, manganese and silver, sulphur hexafluoride, boron trifluoride gas, and boron trifluoride complex.

As will be noted from the illustration of the stand, the display included a number of interesting zinc-base die castings—in the "as cast," plated, and chemically protected conditions—samples of brass, and examples of zinc coatings applied by electroplating and by hot-dipping. Pigments, zinc oxide and lithopone, so essential in the manufacture of paint and rubber products, were also featured on the stand.

THE Iron & Steel Corporation of Great Britain have notified the Birmingham Small Arms Co., Ltd. of their intention to exercise their option to acquire the steel interests of the Birmingham Small Arms Group consisting of Wm. Jessop & Sons, Ltd., J. J. Saville & Co., Ltd. and Bromley Fisher & Turton, Ltd.

Negotiations on price and date of transfer are proceeding between the representatives of the Corporation and the Birmingham Small Arms Co., Ltd.

The British Instrument Industries Exhibition

STAGED with the patronage and active support of The British Electrical and Allied Manufacturers' Association, The British Industrial Measuring and Control Apparatus Manufacturers' Association, The British Lampblown Scientific Glassware Manufacturers' Association, The Drawing Office Material Manufacturers' and Dealers' Association, and The Scientific Instrument Manufacturers' Association of Great Britain Limited, the first exhibition devoted exclusively to the British Instrument Industry was held in the National Hall, Olympia, from July 4th to July 14th.

Whilst it would be true to say that the majority of the exhibits were applicable to the metallurgical field, whether on the laboratory or plant side, limitations of space compel us to take rather a narrower view and deal only with those most closely concerned with the industry.

The Exhibits

Bailey Meters and Controls, Ltd.—The exhibits of Bailey Meters comprised instrument panels, and indicators, recorders and controllers for the measurement and control of such factors as flow of steam, water, oil, air and gases; pressure; temperature; draught; level, etc. One panel of particular interest was laid out for the control of a reheating furnace normally fired by gas, but provided with oil boost in case of gas shortage, as may arise in integrated works.

Baird & Tatlock (London), Ltd.—B.T.L. metal unit laboratory furniture was featured in this company's display on the composite SCIEX stand, and a selection of laboratory installations equipped with metal and wooden fittings was shown by means of photographs. Amongst the general chemical exhibits a recent development shown was a magnetic stirrer combined for the first time with a hotplate. Apparatus for coal testing, oil testing and gas analysis was displayed in the industrial equipment section, together with a re-designed metallurgical polisher, carbon and hydrogen furnace, and electrolytic apparatus. Of special interest was a new development—an electrographic spot-test apparatus for sorting and checking materials in workshop and stores—shown in laboratory and pocket models.

Baldwin Instrument Co., Ltd.—Included in Baldwin's exhibits were a number of instruments concerned with the measurement of material thickness. The "Atomat" beta-ray thickness gauge uses a radioactive isotope of four years useful life, in conjunction with an indicating instrument calibrated in thickness or weight; it may be used with paper, board, plastics, metal foil, etc. Mainly for laboratory use, there is a portable battery operated model, the "Atomette," whilst for thicker materials a gamma ray instrument is available. In temper-pass rolling of steel strip, accurate gauge control is essential, and a novel magnetic instrument was shown, which measures the extension during rolling by means of two simultaneous measurements of a magnetic pattern "imprinted" on the steel before it enters the rolls.

R. & J. Beck, Ltd.—Microscopes and accessories formed the main bulk of the exhibits on the Beck stand, although other optical equipment, such as replica diffraction gratings and a number of spectroscopes, was

Beck No. 50 Universal Microscope

also on view. The range of microscopes shown was quite extensive, including monocular and binocular models for research and routine work. Of particular interest were the No. 50 Universal microscope, and the reflecting microscope complete with a series of reflecting objectives. The former has been designed to provide an instrument for visual, projection and photographic examination by all normally used methods.

British Arca Regulators, Ltd.—On this stand was to be seen a range of equipment for automatic control, particularly of gases and liquids. Diaphragm operated valves, relays, thermostats, humidistats and gas pressure regulators, suitable for hydraulic or pneumatic operation, were shown, whilst electrically operated controllers included thermostats, humidistats and relays with motorised steam valve units, together with a recorder-controller.

Cambridge Instrument Co., Ltd.—Pre-eminent among the industrial instruments shown was the comprehensive range of temperature measuring instruments, comprising indicators, recorders and controllers of the electrical resistance, thermo-electric, mercury-in-steel and vapour types, together with radiation and optical pyrometers. On the chemical side were shown, the new Cambridge direct reading pH indicator, apparatus for electro-titration and polarographic methods of analysis, and gas analysis instruments for measurement and control. A new instrument with wide possibilities in industry is the electronic quick-acting recorder which has an exception-

Cambridge Direct Writing Polarograph

ally rapid response speed of 0·5 second ; this was shown as a six-point recorder.

C. F. Casella & Co., Ltd.—The laboratory and industrial instruments shown by this company included manometers, micro-manometers, pressure gauges and recorders, pitot tubes, and airborne dust-sampling apparatus. The latter included several instruments described recently in *Metallurgia*, such as the thermal precipitator, jet dust counter, and cascade impactor.

Chance Brothers, Ltd.—Apart from the "Flame-master" a useful lightweight hand torch, the Chance exhibits comprised a variety of glass products, including optical glasses, ophthalmic glasses, eye protecting glasses for welders, and "Hysil" laboratory glassware.

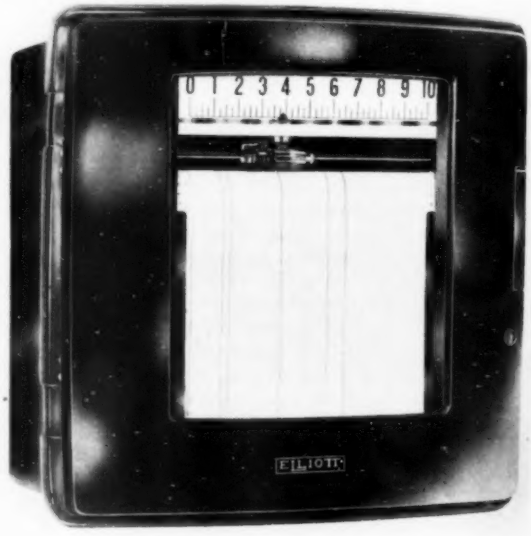
E. K. Cole, Ltd.—For the seeker after radioactive ore, E. K. Cole had on show the Ekco Prod which has a weight of only 3½ lb., no controls, no electronic circuitry and no interconnecting cables except for headphones. Of wider interest was the newly restyled Industrial Thickness Gauge shown as a working exhibit. Based on the absorption of radioactive radiation, it can be used for soft materials and wet or sticky coatings.

Coley Thermometers, Ltd.—This Company specialises in vapour pressure and mercury-in-steel thermometers, and the exhibits included examples fitted with electrical contacts for visible or audible alarms on reaching the pre-set temperature. A demonstration panel showed an indicating temperature controller and a temperature recorder controller in operation ; these are available for steam-, gas-, or electrically-heated equipment.

Cooke, Troughton & Simms, Ltd.—Metallurgical interest on this stand was centred on the Vickers Projection Microscope, which provides for microscopic examination by incident and transmitted light, and for low-power work. Improvements have been made in the fine-focussing movement, and the new desk-style cabinet enables the user to remain seated. Other microscopes shown included a universal microscope, a range of polarizing microscopes (one with the new three-axis universal stage), and stereoscopic microscopes.

Department of Scientific and Industrial Research.—Many instruments designed for use in specialised research can be found uses in industry or other branches of research. On the D.S.I.R. stand, some thirty instruments developed in Government and Research Association laboratories were displayed. They included a disappearing filament optical pyrometer, a pneumatic measuring head for small displacements or surface roughness, and an electronic recording or control micro-meter (N.P.L.) ; a gas content tester for molten metal (B.N.F.M.R.A.) ; a wire-drawing die profilometer, and a differential pressure meter (B.I.S.R.A.) ; a dew-point meter for the investigation of corrosion by small amounts of sulphuric acid in the flue gases of water tube boilers (B.C.U.R.A.) ; and a device for measuring the surface truth of polished or unpolished metal surfaces, (Design and Research Centre for the Gold, Silver and Jewellery Industry).

Doran Instrument Co., Ltd.—The pH instruments shown on the Doran stand included pH meters with an accuracy of 0·01 pH and reliable automatic temperature compensation ; pH indicators for A.C. mains operation ; pH recorders ; and pH electrodes of new and novel design. For temperature measurement, a thermocouple potentiometer was shown, together with a miniature instrument of this type measuring 8¾ in. × 5¾ in. × 5¾ in.



Elliottronic Potentiometer Recorder

W. Edwards & Co. (London), Ltd.—Manufacturers of equipment to cover all aspects of vacuum engineering, showed a range of "Speedivac" rotary and diffusion pumps, together with vacuum gauges and vacuum plant. One of the latest additions to the rotary range is a two stage high efficiency unit (Model 2520) for laboratory work, or industrial applications not calling for high speeds. Included in the plant display were a vacuum coating plant and gas content tester for molten light alloys, designed in consultation with the British Non-Ferrous Metals Research Association. Rapid in operation, samples may be checked for gas content before casting.

Elcontrol, Ltd.—This company specialises in electronic "on-off" or two position controllers designed particularly for industrial rather than laboratory use. The exhibits comprised liquid level control equipment ; furnace safeguard equipment ; process timers ; weld timers ; photo-electric equipment ; temperature control ; and register control.

Electroflo Meters Co., Ltd.—Typical instruments from the Electroflo range were shown, together with a unique

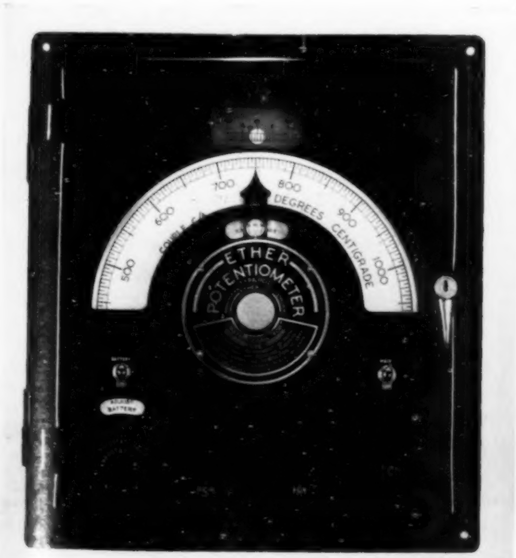
photographic display of the use of instruments in British Industry. The most recent development on show was the Electronic Recording/Controlling Potentiometer. Of the continuous sensing and balancing type, control action is instantaneous with the slightest deviation from the required value. When used in conjunction with the Electroflo hydraulically operated regulator, it is possible to control the largest industrial furnaces.

Elliott Brothers (London), Ltd.—This old-established firm, besides showing its range of electrical measuring instruments, had a number of exhibits concerning process control. These included recorders; automatic controllers; indicators; pyrometers and thermometers; flowmeters and pressure recorders; gas analysis equipment; and humidity meters. Other exhibits which may be mentioned were the 'Elliottel' system of remote indication and control; magnetic amplifiers suitable for use with thermocouples; and 10-channel strain display equipment.

Ether, Ltd.—On this stand, also, the main emphasis was on temperature measurement and control. The instruments shown comprised a proportioning controller, particularly suitable for electric furnaces; an anticipatory control device; a combustion safeguard for service in gas- and oil-fired furnaces; and a range of motor- and solenoid-operated gas and air valves. Also shown were a wall-type potentiometer; a widestrip potentiometer; molten metal pyrometers; surface contact pyrometers; optical pyrometers; etc.

Evans Electro-selenium, Ltd.—Two items of particular interest were shown on this stand. The first, the E.E.L. absorptiometer, is suitable for colour-matching, turbidity and opacity measurement, and the determination of trace elements, while the second, the E.E.L. portable colorimeter, provides a simple photo-electric means of assessing the colour density of a liquid.

Evershed & Vignoles, Ltd.—The principle exhibit on this stand was an Evershed Centroller, which is a self-contained unit for the centralised operation of process plant, and comprises a console, or desk, in which are concentrated the many controllers and recorders necessary for the efficient operation of such plant. It also has a control diagram having a number of miniature edgewise indicators inserted at appropriate points of measurement. Other new apparatus on view included a process controller, an electro-pneumatic relay and a flow-meter.



Ether Wall-Type Potentiometer

Foster Instruments Co., Ltd.—The range of equipment for temperature measurement shown covers the entire field of temperatures likely to be encountered in industrial or research work. Amongst the exhibits were single and multi-point temperature indicators and recorders for use with both thermo-couple and resistance thermometer elements; automatic temperature controllers; optical and radiation pyrometers for temperatures up to 3,000° C., and portable testing equipment. A range of Introscopes was shown for the internal examination of bores from $\frac{1}{8}$ in. diameter to large models which can be made to operate to a depth of 30 ft.

A. Gallenkamp & Co., Ltd.—A wide range of laboratory apparatus on the Gallenkamp stand featured "Technico" volumetric glassware; A.G. sintered filtration apparatus, including crucibles, funnels, gas washing apparatus, and immersion filters in six grades of porosity; A.G. standard joint glassware; and a selection of miscellaneous items. Among the latter were to be found tube and muffle furnaces, low-temperature ovens, hotplates, stirrers, electrically heated water baths, etc.

The General Electric Co., Ltd. and Salford Electrical Instruments, Ltd.—Apart from the more generally applicable exhibits on the G.E.C. stand, there were one or two of particular interest to readers. For instance the magnetic sorting bridge shown has many possible applications, chief among them being the checking of materials in stores and workshops. Also shown were the laboratory and pocket layer thickness meters, and instruments in the field of remote indication and control.

W. & J. George & Becker, Ltd.—Among the balances to be seen on this stand, was the "Nivoc" Automatic Aperiodic Balance whereby weighings of up to 200 g., accurate to 0·1 mg., may be obtained rapidly by simple manipulation of the balance controls. For locations where the vibration problem is acute an anti-vibration balance table was shown. Other exhibits included a range of laboratory equipment and the "Kemiframe" system of laboratory scaffolding for the support of experimental apparatus.

Glass Developments, Ltd.—Perhaps the most interesting of this Company's products is the Ultrasonic Flaw Detector. In this instrument, instead of an echo being made to deflect the time base vertically, it is used to brighten it. If the time base is moved vertically in synchronism with the movement of the probes across the surface, and a persistent type screen is used, a sort of "ultrasonic image" of the specimen is built up on the tube face. For this new development, it is claimed that more echo data can be presented per unit area of screen or photograph, and that the presentation of an ultrasonic image in this way aids the judgment in assessing the relative importance or seriousness of different flaws.

James Gordon & Co., Ltd.—Included in the Gordon display was a selection of Mono Combustion Recorders suitable for use with industrial furnaces and processes where accurate, automatic, continuous gas analysis is essential. Another interesting exhibit was the Type

A640 Servometer which is used for operating valves, dampers, and other components of an automatic control system which require power greatly in excess of that provided by the Standard Servomotor.

Griffin & Tatlock, Ltd.—Three items of metallurgical interest were shown by Griffin & Tatlock, namely, a modified Ströhlein apparatus for the determination of carbon in steel; a heavy element tube furnace for operation up to 1,150° C. and even up to 1,200° C. for a very short time; and a novel metallurgical mounting press. In this press there are no oil feed pipes to split, washers to leak, or separate tongs for heating and cooling. The whole instrument is complete in itself with built-in heating and cooling coils, and sufficient pressure for the production of homogeneous mouldings is obtained by hand-pressure on the tommy bar attached to the pressure screw.

Hanovia, Ltd.—This company, which specialises in ultra-violet equipment, had on show a representative range of technical lamps for a wide variety of industrial applications. These included two portable fluorescence lamps for the detection of leaks in refrigerators, condensers, etc., and for the crack detection of metals by the fluorescent pentrant method.

Hilger & Watts, Ltd.—The Hilger Division, in an attempt to keep a balance between their more everyday products and those for use in advanced laboratories, included several exhibits of interest to the metallurgist. Hilgers have been pioneers in this country in the design and production of photo-electric absorptiometers for carrying out colorimetric methods of analysis, and in this field the latest Spekker was exhibited. On the spectrographic side, the medium quartz spectrograph and the fully automatic large quartz and glass prism spectrograph, suitable for use in non-ferrous and ferrous analysis, respectively, were of special interest. Of interest, too, was the H.R.X. Diffraction Unit, whose four-window X-ray tube, with the simple means of varying the nature of the radiation at each of them independently, not only allows four separate experiments to proceed simultaneously, but enables the user to select optimum conditions for each.

Honeywell-Brown, Ltd.—Brown "Continuous Balance" Electronik Potentiometers, by replacing conventional galvanometer and cyclic balancing mechanisms with a simple self-contained amplifier assembly, provide continuous balance, with high sensitivity and simplified and rugged construction. Models exhibited included circular and strip-chart, recorders, indicators, and controllers of the single and multipoint types, one of particular interest being a liquid steel temperature recorder. Also shown were "Protectoglo" combustion safety systems, providing instantaneous shut-down on flame failure.

Industrial Pyrometer Co., Ltd.—A full range of Industrial Pyrometers was displayed, comprising edgewise indicators, portable indicators, foundry indicators, rotary switches, rotary switch indicators, indicating controllers, recorders, and recording controllers. Most of the range are made in a number of sizes to be in keeping with the size and cost of the plant on which they are to be used.

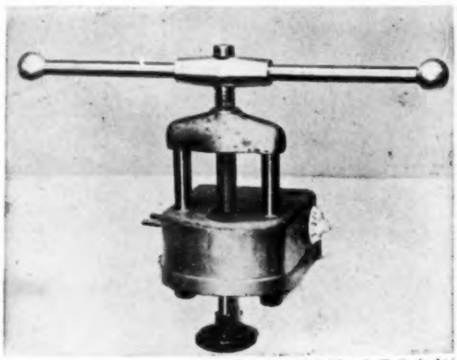
Kelvin & Hughes, Ltd.—Of particular interest was the Mark IV Supersonic Flaw Detector, specially designed for the non-destructive testing of ferrous and non-ferrous metals, which has now been developed to the stage where application can readily be made to the testing of welds in welded pressure vessels, and the testing of locomotive axles and other materials prior to fabrication. Other exhibits within our field included a 4-channel Dynamic Strain Recorder, and a range of boiler-house equipment, some items of which—the temperature measuring and controlling gear, and the flue-gas analysing equipment—are applicable to furnaces.

George Kent, Ltd.—The stand comprised six separate sections, each allotted to a specific industry: steam power, steel, oil, chemicals, sugar, and water. Automatic control of steel works plant has found increasing favour in recent years, and the main display in the steel section was a special lighted exhibit comprising diagrams showing a typical instrumentation scheme at present in use at a large steel works in this country. Other exhibits in this section included a roof temperature controller and a furnace pressure controller. Also to be found on the Kent stand were the new glass electrode *p*H recorder, with flow channel and immersion types of electrodes, and a working example of the new oxygen recorder.

Marconi Instruments, Ltd.—For the determination of the thickness of plating, paint or other covering deposited on a ferrous base, without damaging the surface, Marconi had on show a thickness meter operated by A.C. mains. No valves are used, the functioning depending directly upon reluctance variations in a magnetic circuit. Other interesting exhibits included a range of *p*H meters: these comprised a battery-operated portable model, and battery- and mains-operated models suitable for the measurement of small potentials developed by electrochemical action.

May & Baker, Ltd.—Special attention was paid, on the M. & B. stand, to Ethulon, a tracing film whose dimensional charges with variation of atmospheric humidity are small and equal in all directions; it does not discolour or become brittle with age. Among the photographic products, Planocop, a high-speed document copying developer was of special interest. The display also included a wide range of laboratory chemicals.

Metropolitan-Vickers Electrical Co., Ltd.—For the metallurgist, the exhibit of outstanding interest on the M.V. stand was, undoubtedly, the electron diffraction camera, which provides facilities for observing and measuring the conditions of surfaces, or thin layers of materials, by examination of the diffraction pattern obtained from a reflected or transmitted electron beam. Special features are the manipulator which may be rotated, tilted or translated with respect to the electron beam; the hot-cathode biased electron gun giving maximum intensity compatible with small spot size;



Courtesy of Griffin & Tatlock, Ltd.

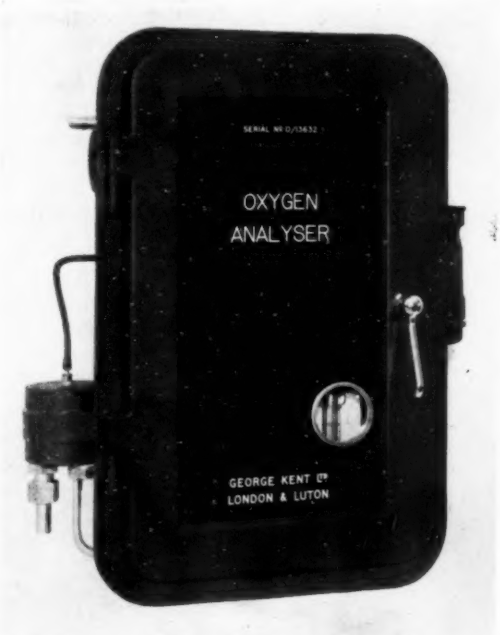
Metallurgical Mounting Press.

and the stabilised D.C. set supplying 25 kV, 50 kV, 75 kV and 100 kV.

Mullard, Ltd.—Included in the electro-chemical instruments shown by Mullard were a new polarograph in which the current to a dropping mercury electrode is continuously measured by electronic means, a conductivity bridge and a conductivity controller, and potentiometric titration equipment. Interest was also to be found in the field of ultrasonics, the exhibits comprising a high-frequency quartz crystal generator, a low-frequency magnetostriction type generator, an ultrasonic soldering iron, and an ultrasonic soldering bath.

Murex, Ltd.—The excellent corrosion resistance and getter properties of zirconium and tantalum, whose commercial scale production has been commenced by Murex within the last year or so, make them especially interesting to the instrument maker. Samples of these metals were shown, along with tungsten and molybdenum in forms not previously obtainable. Other exhibits included sintered permanent magnets and sintered composite magnets in which the iron pole pieces are sintered together with the magnet.

Nash & Thompson, Ltd.—For mounting metallurgical specimens in plastics, a press based on a B.N.F.M.R.A.



Kent Oxygen Analyser

design was on show. The cylinder and ram are in a single unit, so that mould formation and ejection are axial, thus minimising wear on the cylinder and ram. A 750-watt heater gives rapid heating, and a water coil is mounted in the cylinder wall. Another interesting exhibit was the temperature controller based on a platinum resistance thermometer and Wheatstone bridge circuit, used in conjunction with a thyratron valve. The controller is designed to switch currents up to 15 amps. and to have a temperature differential of 2° C. between 0° and 1,000° C.

Nucleonic and Radiological Developments, Ltd.—The

Courtesy of Nash & Thompson Ltd.

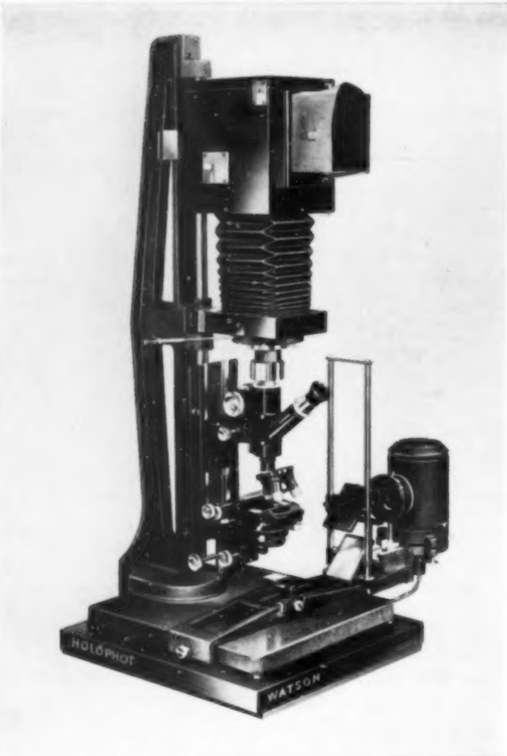
Metallurgical Mounting Press

regular processing of large numbers of X-ray films presents something of a problem, one solution of which was demonstrated in the form of a working model of the N.R.D. Automatic X-ray Film Processing Unit. In this equipment the films, in hangers, are passed through the appropriate developing, fixing and washing tanks automatically, consistent processing being thereby ensured.

L. Oertling, Ltd.—The Oertling display showed the latest developments in chemical, microchemical and assay balances. Fitted with corundum planes, the Model 62FM balance is designed for speed of operation, using automatic weight loading, and will retain its precision and sensitivity for many years. The stability of the micro-chemical balances (141 & 142) is excellent, and Model 142 is unique in having a sensitivity of 1 microgram per division and being at the same time aperiodic. Models 161 and 162 assay balances satisfy the demand for high-speed balances for this purpose.

Short & Mason, Ltd.—The main exhibit consisted of a graphic panel, embodying the completely new series of Transet recording and indicating receivers, which occupy a panel space of only $4\frac{3}{8} \times 5$ in., have a built-in auto-manual control and roll type charts. These instruments were connected up to provide a working demonstration of the S. & M. " Transet " system of pneumatic transmission for graphic panel installations. Also on show were a comprehensive range of indicating, recording and controlling instruments, and a number of high-grade standard laboratory thermometers.

Sifam Electrical Instrument Co., Ltd.—The portable pyrometer shown by Sifam is a $3\frac{1}{2}$ in. scale moving coil instrument mounted in a case together with an ambient temperature thermometer. Normally supplied 0–200° C. and 0–400° C., the indicator can be supplied in single or



Watson "Holophot" Photomicrographic Equipment

double ranges up to 1,600° C. One of the most valuable features of the instrument is its speedy response.

Stanton Instruments, Ltd.—A complete range of precision balances, from a simple inexpensive free swinging instrument to a micro-balance with a sensitivity of 0·001 mg., was displayed, along with heavy-duty balances, auto-loading balances, and analytical and heavy-duty weights. Shown for the first time were new features and improvements incorporated in the Stanton aperiodic balances, notably the redesigned weight-loading attachment which gives positive fingertip control in weight application even for the heaviest weights. The newly developed Precision Limit Balance was also on view.

Sunvic Controls, Ltd.—In addition to a complete range of temperature control and electronic apparatus, Sunvic arranged a number of demonstrations illustrating some of the uses of their equipment in research and industry. These included a creep test control panel incorporating an improved type resistance thermometer controller, giving automatic compensation for mains voltage variation without change in control temperature; a strip chart recorder with a high speed response (1 second full scale) and efficient damping; a radiation pyrometer whose response to a rapidly changing temperature was demonstrated; and a cold junction thermostat.

Taylor, Taylor & Hobson, Ltd.—Among other 'Taylor-Hobson' products displayed was the 'Flying Mike' Continuous Gauge which is used in cold-rolling mills to control, within close limits, the thickness of strip metal. The gauging points are in continuous contact with the surface of the travelling strip, and error in thickness is instantly detected, magnified and registered on the meter dial. Other exhibits included the Mod. 3 'Talysurf,' and the Taylor-Hobson Toolmakers' Microscope.

The Telegraph Construction & Maintenance Co., Ltd.—The materials requirements of the instrument maker are somewhat specialised, and on the T.C.M. stand a display of special materials was made. These included magnetic alloys such as "Mumetal," "Rhometal," etc.; electrical resistance alloys—"Telcuman," "Telconal," etc.; thermostatic bi-metals; alloys with controlled thermal expansion; beryllium copper; and special alloys. Apart from the materials themselves, examples of their applications were shown.

J. W. Towers & Co., Ltd.—Of outstanding interest in this display of laboratory equipment were the new Towers automatic balances. The Model 200 automatic direct reading balance is novel in that the load on the beam is always brought to 200 g. at every weighing by removing weights equal to that of the sample. All weights down to 0·1 mg. are controlled by four external knobs. For weighing heavy samples, the new Model 7 rotating weight balance was shown. This device covers 0–1,000 g. at 0·5 g. intervals: total capacity is 6kg. Other exhibits of interest included low temperature ovene and Lablox support frames designed to eliminats numerous retort stands.

Townson & Mercer, Ltd.—The equipment of most direct metallurgical interest shown by T. & M. was the Strohlein apparatus for the rapid estimation of carbon in steel or ferro-alloys. A chart is provided from which corrections for variations in temperature and pressure can readily be seen. Also displayed were low-temperature ovens, metal desiccators, thermostat baths, shakers, decalorisers, all-glass, strip action stills, polythene squeeze wash bottles, etc.

20th Century Electronics, Ltd.—Of particular interest on this Company's stand was the new Geiger Counter Tube, Type X.10H for X-ray spectrum analysis. This has been specially designed by Dr. U. W. Arndt of the Royal Institution to have the highest performance for Cu Kα X-rays in crystallographic work.

Viscons, Ltd.—Included in the Viscon display were chemical balances, general laboratory apparatus, volumetric glassware, lampblown glassware, and a range of standard ground joint apparatus. Also shown was the "Soundmirror" magnetic tape recorder.

Walker, Crosweller & Co., Ltd.—The Arkon Model 1600 pressure and vacuum recorder shown is a new instrument for the measurement of pressure, draught, or combinations of both. The design gives a simple powerful movement which, combined with robust construction, makes the instrument suitable for operation in difficult conditions as in gas works, coke oven plants, steel works, foundries, etc.

W. Watson & Sons, Ltd.—The full range of Watson microscopes shown included their new series of stereoscopic microscopes which have a special appeal to industrial machine shops and laboratories. Of particular interest, however, was the "Holophot" photomicrographic equipment which fulfils the demand for visual microscopy and photomicrography with transmitted light, dark ground illumination, oblique top lighting, or vertical illumination. Furthermore, the equipment can be used for macrophotography up to a magnification of $\times 10$. A sponge rubber anti-vibration pad is fitted under the heavy metal base plate, and for particularly bad locations, a special base can be supplied.

IRON AND STEEL SUPPLEMENT

This year has seen the most fundamental change the industry has yet undergone—the taking over by the publicly-owned Iron and Steel Corporation of practically the whole of the iron and steel producing plants in the country.

Quite early in its career, the new Corporation is faced with a raw material problem which is likely to prevent the record outputs of last year being repeated. This situation gives point to the argument that it is useless to build plant to a capacity of 25,000,000 tons per year if raw materials for only 16,000,000 tons are available. The steelmaker can no more make steel without his raw materials than the ancient Hebrews could make bricks without straw. In the first article in this supplement, a Special Contributor discusses the causes of the shortage and makes reference to future prospects.

The operation of the blast furnace is very dependent on the type and quality of the ore which it is required to smelt and in the second article, Mr. R. P. Towndrow, of Colvilles Ltd., discusses present-day trends in blast furnace practice, paying particular attention to the importance of ore preparation.

A number of interesting metallurgical problems arise in the production of steam turbine rotors and turbo-alternator rotors, involving as they do the forging of exceptionally large ingots. The procedure adopted in the manufacture, inspection and testing of these forgings is discussed in an interesting article by Mr. H. H. Burton, of E. S. C. Ltd.

Finally, the behaviour of the finished steel under certain conditions of localised heat treatment, such as obtain in flash butt welding, for instance, is dealt with by Professor O'Neill, who discusses apparent abnormalities in certain steels in the light of the isothermal transformation diagrams.

The Raw Materials Problem

By a Special Contributor

The Iron and Steel Industry is facing a very difficult period due to the difficulty in obtaining sufficient raw materials to keep the plants running to capacity. The events leading up to this state of affairs are analysed, and reference made to the steps being taken to ensure future supplies of ore. In conclusion, the author gives a brief account of home ore recovery.

AFTER a prolonged spell of record-breaking activity, the steel industry is experiencing a temporary decline. Not a serious fall, but now that British industry is geared to steadily increasing steel production, any falling away is bound to have serious repercussions.

With the approach of a period of stringency, some form of rationing will obviously be necessary. Allocation schemes are being prepared for iron and steel, other than sheet steel and tinplate which are already subject to allocation. These will take some months to work out, and in the meantime interim measures are being introduced to safeguard supplies for the defence programme, essential exports, and other vital steel-consuming projects, such as the fuel and power programmes. For orders for specialised defence equipment, a "Defence Order" symbol consisting of the letters "D.O." will be applied to the contracts, whilst a "Preferential Treatment" scheme will be applied to essential civilian requirements. That the short fall in total supplies is not likely to amount to more than about 10% only serves to illustrate once again the truth of Mr. Micawber's famous recipe for happiness—"Annual income twenty pounds, annual expenditure nineteen, nineteen, six, result—happiness. Annual income twenty pounds, annual expenditure twenty pounds ought and six, result—misery."

With capacity to-day in the neighbourhood of 17,000,000 tons per annum, while the requirement for 1951 appears to be between 16,250,000 and 16,750,000 tons, it may well be asked has anything gone wrong with the industry's calculations, especially as the indications are that the industry will do well if it produces 16,000,000 tons this year. But capacity is one thing, output is another. With the best will in the world, steelmakers cannot make steel without adequate supplies of raw materials.

Annual Requirements

What are these raw materials? The industry depends on ample supplies of iron ore, scrap, coke and limestone, and the carrying of these materials is a major operation, whether abroad, within this country, or within the works.

The tonnage involved is roughly 40,650,000 tons made up as follows:—

Imported Ore	8,000,000 tons
Home Ore	12,000,000 ,,
Scrap	10,500,000 ,,
Coke	10,500,000 ,,
Limestone	650,000 ,,

Every week the total consumption figures of all these materials are returned by the works to the British Iron and Steel Federation, which in turn advises the Ministry of Supply. Likewise stocks at works, so that at any given moment the exact position is known. As the same people are responsible for laying down additional capacity, it is reasonable to suppose they would take into account the increased raw material requirements entailed. This in fact is done by a Raw Materials Committee set up by the British Iron and Steel Federation at the end of the war when the industry's big post-war development plan was agreed.

So far as the actual purchase of raw materials is concerned, in the case of imported iron ore and scrap, this is the concern of the British Iron and Steel Corporation and its subsidiary British Iron and Steel Corporation (Ore) Ltd. They are responsible for long-term planning in this field, including the provision of the necessary shipping, and have to see that the iron ore or scrap, as the case may be, is delivered as required in compliance with the instructions of the Raw Materials Committee.

In particular, during the past two or three years, while new blast furnace capacity was being constructed, the Corporation was especially concerned with the securing of ample supplies of German scrap. This work was done in conjunction with the Government, and the success which attended the Corporation's efforts in this direction helped materially in securing record output by the industry. At the same time, in co-operation with the French, big developments at Conakri on the west coast of Africa were being carried out. This area alone should be capable of sending Great Britain an additional million tons of iron ore annually by the beginning of 1953, and a long-term agreement has been reached in Newfoundland with the Dominion Steel Co., as a result of which a million tons of Wabana ore will be obtained per annum as this project develops. New ore ships to carry the extra tonnages are being built.

While the Corporation was dealing with these external requirements, the industry was proceeding apace with the development plan—new blast furnaces—new steel furnaces—new finishing capacity—new coke ovens. In particular the great Abbey Works, with a capacity of a million or more tons of steel, is approaching completion. Additional blast furnace capacity for handling increased supplies of ore has been created at the Abbey Works, at Scunthorpe, on the Clyde and elsewhere. Before the end of the year additional coking capacity will be in operation capable of producing a further million tons of coke annually, whilst at Corby new ore recovery plant is coming into operation capable of greatly increasing ore output from the Northamptonshire bed.

The Shipping Problem

This is an encouraging picture. What then had happened to send matters awry? The answer is—shipping. Iron ore freight is a dirty business and not particularly remunerative at the best of times. It is not regarded with any particular favour by shippers and in that respect has a lot in common with the coal export trade. Traditionally this joint problem was overcome by using the same ships for both jobs, i.e. the coal boat went out with coal in its bunkers and came back with iron ore. When coal export after the war failed to recover, the economic balance of this trade was seriously affected, with the result that freight rates for both coal and ironstone went up rapidly. This position was greatly exaggerated with the outbreak of the Korean war, when available tramp supplies steadily diminished, not only because shipping was needed for the carriage to Korea, but also because the long haul kept ships tied up very much longer. On top of this the coal crisis in England last winter drained off what shipping there was left, and the ironstone trade was left practically ship-less.

Without the new coking capacity due to come in this year, any great increase in the use of native low iron content British ore was out of the question, and the steel industry therefore commenced to use its raw material stocks on a scale which made rapid reduction inevitable. The supply of steel has indeed been maintained since last summer by heavy drains on stocks of iron ore, pig iron, scrap and half-finished steel in the steel works, and on the stocks of finished steel accumulated by consumers.

Home Ore Recovery

As the industry in Britain may well become increasingly dependent on home ore supplies a brief account of its recovery may not be out of place.

Apart from the limited deposits of rich hematite ores (containing about 50% of iron) in Cumberland and Glamorgan, which are used for special purposes, there are three main deposits of ore in England. These are in the Cleveland Hills, in the north-east ; near Scunthorpe, in north Lincolnshire ; and a band which runs from central Lincolnshire across Leicestershire, Rutland and Northants. None of these three averages more than about 30% iron, and much of it contains less.

The ironstone may be " got " by open-cast quarrying, or by mining. The former accounts for the bulk of the tonnage in this country, and has developed from " plank and barrow " methods, appropriate where the over-burden did not exceed about 20 ft., to the modern use of giant excavators, which can quarry a seam lying 80 ft. or even more, below the surface. At greater depths the ironstone has to be mined, and this is, of course, a more expensive business. Not only is there the obviously greater complexity of mining technique, and the need for using ten times more men, but only 75% of the ore can be extracted, against 100% in open-cast working.

Of the 14,000,000-ton total, nearly 2,000,000 tons of British ore comes from deep mines. The earliest mines were horizontal " drifts " driven straight into the side of a hill, but the last drift closed down in 1949, at what was at one time the biggest ironstone mine in the world. One of the deepest mines now in operation is in the Cleveland Hills—720 ft. to the foot of the shaft. A double line of track runs to the working face, a quarter of a mile from the shaft. Holes for the charge are drilled by compressed air drills, the stone is blasted away from the rock and a compressed air-operated shovel loads it into the trucks.

The men work in teams of four, two on the drills and two on the loader. Between them they shift an average of 100 tons of ironstone per day. Mining is by " bord and pillar," in which tunnels or bords are driven out from the bottom of the shaft, leaving pillars between them to support the roof. Timber props are used when necessary. When the bords have been cleared of ironstone there is a " second working " to remove the pillars. As they come out, any timber props used are crushed like matchsticks.

The Outlook

The indications are that the drain of stocks is now ending, and indeed as shipping improves, some build-up should take place in the autumn. In the meantime, the works are making do with such scrap as they can obtain from local sources, by changing the burden in the blast furnaces so as to use more home ore, and, when all else fails, using lost time to carry out maintenance work on temperarily closed furnaces.

A home scrap drive aimed at recovering an additional 500,000 tons of scrap this year is well under way, and present indications are that it will be successful. The leaders of the industry are satisfied that the decline in output is only temporary and that the upward trend of production will be resumed fairly soon.

Trends in Blast Furnace Practice

By R. P. Towndrow, M.Sc.

Manager, Colvilles Ltd., Clyde Iron Works

The very nature of the blast furnace process tends to a policy of conservatism in its operation. Nevertheless considerable progress has been made over the decades and is probably as rapid to-day as ever it was. More and more attention is being devoted to preparation of the ore before charging with a view to improving the performance of the furnace, and these and other aspects of present day trends are discussed by the author.

IN many instances the practical application of research investigations into blast-furnace practice is of a long term nature. This is mainly due to the comparatively infrequent opportunities afforded by the operating circumstances of a blast-furnace plant for interference with its normal production for the purpose of experimental observations or alterations to its structure, coupled with the complexity of variables which make difficult the ready deduction of results from any deliberately introduced change of conditions. Present-day trends, therefore, are by no means necessarily the putting into practice of new found ideas, but represent, in the main, the consolidation of many years of experience and the development of principles which have, on the theoretical side at any rate, been known for a considerable time. The considerable volume of new construction which succeeded the termination of World War II has, however, given an opportunity for considerable expression of the latest developments in blast-furnace technology.

Furnace Size

The size of individual blast furnaces must bear some relation to the magnitude of the steelmaking processes with which they are associated. For example, it is within the bounds of technical possibility to produce 12,000 tons of pig iron per week in a single blast furnace, and there are many steel works for whose operation such a quantity of iron would be sufficient. It is, however, clear that where the blast-furnace gas is used as a fuel in the subsequent processes, the total interruption of supply when the furnace is stopped, either for minor repairs such as tuyere changing and other maintenance items, or for major stoppages such as relining, would have catastrophic effects on the operation of the steel works. Some alternative supply of fuel must be available which will take the place of the gas supplied by each individual blast furnace, although this can be supplemented to some extent by the use of gas holders. Practical limits, however, indicate that it is rarely possible to provide a gas holder capacity greater than the production of one blast furnace for approximately one hour. The size of individual furnaces must therefore be closely related to the size of units which can readily be supplied with an alternative fuel to blast-furnace gas. In this connection it must be admitted that there are numerous instances in the United States of large single blast furnaces working in conjunction with steel works, but it is commonly found under such circumstances that most of the surplus gas is utilised in steam raising, and in such cases the steam is converted to electrical power which can readily be supplemented from a public supply at times when the furnace is out of commission.

Fig. 1.—Modern blast furnace at Clyde Iron Works.

It has been shown by McCance[1] that the size of all steelmaking units, and, hence, of their associated blast furnaces, bears a calculable relationship to the magnitude of the productive capacity of the industry on a national basis, and that such a relationship holds good both in Great Britain and in the United States. To some extent, therefore, the comparatively small size of British blast furnaces, hitherto, reflects the considerable sub-division of our steelmaking industry into comparatively small operating groups, and this allocation of blast-furnace sizing had not, prior to World War II, overtaken the considerable rationalisation which took place within the steel industry. Since the war, however, few blast furnaces have been built with hearth diameters of less than 20 ft. Such furnaces have a coke burning capacity of not less than 4,000 tons per week and an iron making capacity which is, of course, related to the

1 Cleveland Scientific and Technical Institution Third Harold Wright Lecture.

Fig. 2. Controls for automatic charging equipment.

coke burning capacity in terms of the coke consumption per ton of iron. Thus, such a furnace producing iron with a coke consumption of 16 cwts. per ton will be capable of making 5,000 tons of iron per week. Some units of considerably greater size than this have been built in Great Britain and have, in fact, been operating for a number of years. The largest furnaces operating in the United States at present are of the order of 28 ft. hearth diameter and it remains to be seen whether in this country the operation of such large units can be successfully integrated with steel-producing units at present prevailing.

It is well known that the coke burning capacity of a blast furnace is not proportional to the area of the hearth but rather to the area of an annulus immediately in front of the tuyeres, the exact width of which is still the subject of some controversy. It, therefore, becomes apparent that the productivity of a blast furnace does not increase proportionately to its size, and some consideration has to be given to the capital costs of increased unit size in relation to the increased production which becomes available. Against this heavy capital cost is offset the higher productivity per man hour of the large blast furnace. Unless some very large unforeseen change takes place in the overall magnitude of the British pig iron industry, it seems probable that furnaces in the neighbourhood of 23 ft. hearth diameter will be the largest unit generally adopted, except in the case of one or two exceptionally large steelmaking organisations.

Constructional Aspects

On the constructional side, the main engineering details of the furnace have become almost standard. Charging is almost universally carried out in new construction by the twin skip hoist and McKee revolving distributor automatically controlled (Fig. 2). Cooling of the furnace stack is carried out by means of water-cooled copper blocks, and the cooling of the hearth is carried out by water-cooled cast-iron staves. The use of steel columns instead of cast-iron columns is almost universal, and the replacement of riveted construction by welded construction is common.

Perhaps the most interesting development on the constructional side is the use of carbon as a refractory material, the most intensive example of which is exhibited by the all carbon furnace described by Chesters *et al*[2].

In the field of more conventional refractories, increasing use is being made of a so-called " super-duty " hard burnt brick of high alumina content in an endeavour to secure longer lining lives and freedom from hearth breakouts. Considerable room for improvement appears to exist in the methods for construction in carbon, and it is probable that those who have previously had satisfactory experience with fire-clay refractories will be reluctant to depart from their use, while those who have had considerable trouble with hearth breakouts will more readily avail themselves of the knowledge and experience now gained in the use of carbon. as a constructional material for blast furnaces.

Ore Preparation

In various types of practice there exists in the furnace a varying approach to equilibrium, both thermal and chemical, between the ascending stream of reducing gases and the descending burden materials. Since the efficiency with which the fuel is utilised depends entirely on the closeness of approach to equilibrium, much attention has been devoted over many years to various methods whereby a closer approach can be secured. That which has had the widest field of application consists in the more careful preparation of the ores before charging into the furnace.

Fig. 3 illustrates in the form of a family tree the inter-relationships between various forms of research activity and development directed towards the above ends.

It is obvious that gross irregularities in the size distribution of the ore particles will result in inefficient operation. In the extreme case, where the ore burden consists largely of fine particles, the gas stream tends to flow through the bed along channels of least resistance, leading to very inefficient heat transfer coupled with a violent and irregular movement of the column of material. The main principle on which ore preparation rests, therefore, is to remove as far as possible the fine material, and to reduce also the size range of the remaining material, due regard being paid to the fact that the further this size range is decreased by crushing operations the more fines remain to be screened out of the burden. The fine materials so screened out have to be further prepared for smelting by some form of agglomerating process.

Sintering. The large scale on which this operation has to take place has been most favourably dealt with by sintering plants of the continuous down-draft type. Batch-type sintering processes, nodulising kilns, and other methods of agglomeration have also played their part. By virtue, however, of the major part played by sintering, considerable research attention has been directed to the sintering process and many aspects of this difficult problem are now becoming clearer. Most large new blast-furnace installations have been equipped with facilities for crushing and screening the ore and

2 *Journal of the Iron and Steel Institute*, **167**, p. 273 *et seq.*

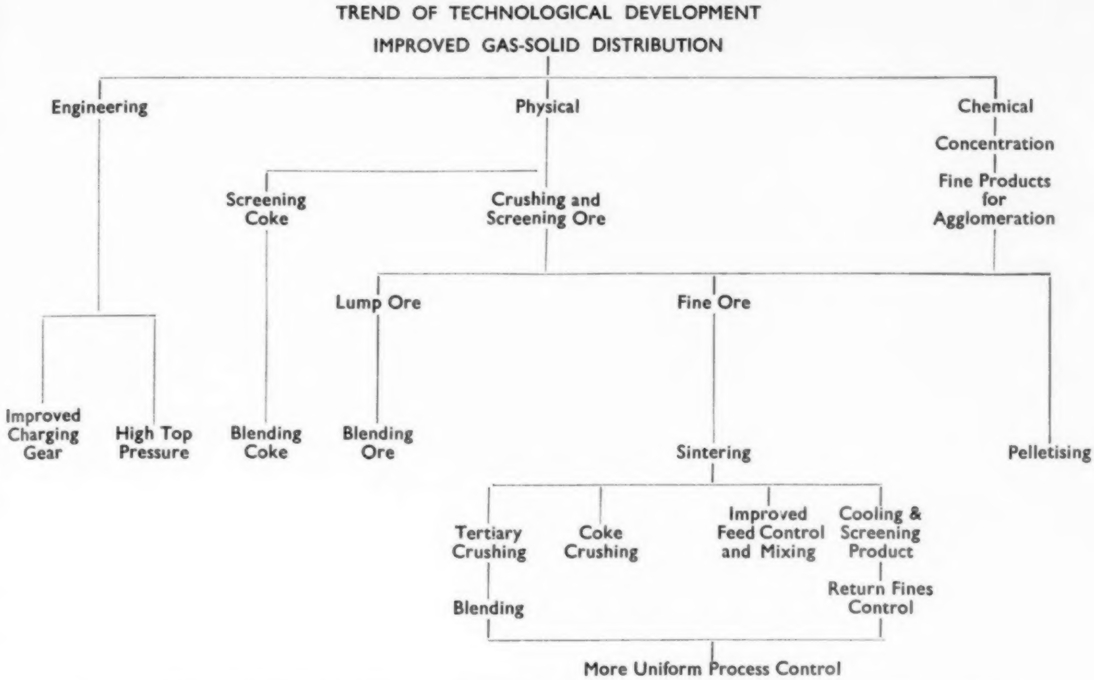


Fig. 3.—Inter-relationship between various forms of research and development activity.

sintering the fines, and in many cases such facilities have been added during recent years to existing plants. In British practice, where the wide variety of materials dealt with ranges from home ores to ores imported from all parts of the globe, a very considerable degree of flexibility has to be provided for in the setting-up of ore preparation equipment. In particular, ample provision has to be made for dealing with the global tendency for the physical quality of available ores to deteriorate. Considerable resources of otherwise suitable ore exist mainly in the form of fines. In addition, the need for materials economy has led to an increasing use for iron making of a variety of iron-bearing materials hitherto regarded with disfavour, such as Pyrites Residues containing a high proportion of sulphur which must be sintered to make them suitable for use in the blast furnace.

In the sintering process, as at present known, compromise has to be effected between carrying out the process at too high a temperature which can result in a non-porous product extremely difficult to reduce, and carrying out the process at too low a temperature which results in a soft friable product which readily breaks down to dust in the blast furnace. Non-uniformity of operation also results in the product containing variable quantities of completely unsintered material which is, of course, as detrimental to the blast furnace, if not more so, than the original fines. A much closer regard, has therefore, been given to sintering as a process in itself. Considerable care is now taken to prepare properly the materials for sintering. For many years it has been the practice to crush the coke breeze to $-\frac{1}{8}$ in., as experience amply bears out that coke breeze of a correct size is a necessity for sintering. Where screening properties of the remaining raw materials make it necessary to pass on to the sinter plant materials of the order of $\frac{5}{8}$ in. to $\frac{3}{4}$ in., attention is being given to the tertiary crushing of the feed in order that all materials entering the sinter

Courtesy of the British Iron and Steel Federation

Fig. 4.—Igniter on Dwight-Lloyd sintering machine of 650 tons/day capacity.

mixture shall not exceed approximately ¼ in. Considerable scope exists for improvement in the design of blending and mixing devices in the sinter feed and new sintering plants are being equipped with very extensive mixing equipment.

A further problem in the production of sinter lies in the cooling of the product. Where the material has to be handled on conveyors, or even through bin gates, too high a temperature of the finished sinter will result in damage to plant, and cooling by water quenching in most cases results in a serious breakdown of the size of the product. Cooling of the sinter can be achieved in two ways, either by providing additional wind box and fan capacity on the sintering machine or by discharging the sinter into some form of a rotary air cooler, of which several examples exist in the United States and Great Britain. The object of this equipment is to deliver the finished sinter at a suitable temperature for handling. More rigorous attention is being given in new installations to the screening of the sinter before delivery to the blast furnace bin. It was previously common practice to discharge the sinter over a fixed bar screen, the fines being delivered as made into the sinter mixture. It is proposed in some installations to introduce mechanical screening of the sinter and to separate the fines into small sinter and unsintered dust. In any case, provision is made on plants of new design for the returned fines to be delivered to an ample surge bin, so that the introduction of the fines into the sinter mix can be controlled at the will of the operator.

Controversy still exists as to the beneficial effects of sinter in the blast furnace burden considered on its own merits, one school of thought tending to regard sinter as a necessary evil in order to make use of the fines from ore screening, others having the opinion that sinter is of itself beneficial material. It seems clear that part of the confusion which exists resides largely in the variation of the quality of sinter from one operation to another. Where the sinter is highly fused and difficult to reduce, or where it is so soft as to crumble into dust, operational difficulties may arise. On the other hand, where the sinter can be made preferably from a single uniform material under carefully controlled conditions, some extraordinary results can be obtained in the blast furnace. In particular, the use of sinter in certain Swedish blast furnaces has resulted in abnormally low coke consumptions, this being attributed by the operators concerned to the highly oxidised condition of the sinter as made. Under normal conditions it is difficult to regulate the relative proportions of ferrous and ferric oxides in the sinter produced, but in the case quoted above the process is conducted in such a way that the iron exists almost entirely in the form of ferric oxide.

Blending.—The methods referred to for improving the physical grading of the blast furnace charge do not of themselves present any means for overcoming variations in chemical analysis. Where the raw materials are of such a nature as to be inherently variable, benefits have been derived from large scale systems for blending the ore in order to reduce these variations to a minimum[3]. At some installations such blending facilities have also been extended to include the coke. Such blending, of course, is additional to the normal blending of coals which takes place at the coke ovens before carbonisation.

Beneficiation.—Mention should also be made of the considerable amount of pilot scale work which is being done on the concentration of some of the less pure iron ores. Fine crushing, magnetic roasting and concentration followed by agglomeration has been applied on a vast scale to the Salzgitter ores in Germany, and at present attention is being given to the concentration of the Taconite ores in the United States, a number of Swedish ores and certain British ores. The ores of Sierra Leone have also proved susceptible to concentration. Unfortunately most of these processes result in an extremely fine product which, by its physical nature, is not well suited to the sintering process, and attention is being actively directed towards pelletising and other forms of agglomeration. This, therefore, does not represent a trend in blast furnace practice so much as a possible forecast of future operation.

Gas Distribution in the Stack

A further line of attack to bring about better distribution of gas and ores in the blast furnace lies in the development of different types of charging mechanism. In this direction there have been countless modifications of the standard conical bell and hopper which have had their day, flourished for a short while, and ultimately been discarded. Several novel forms of distributor have recently reached the stage of a working model, but it would be premature to say that their use could be included as a trend in present operation[4]. There is no doubt, however, that while the McKee distributor gives admirable control over circumferential distribution, the amount of variation which it can introduce into the radial distribution of materials is very small indeed.

As a further alternative to manipulating the size grading of the materials, or the way in which they are placed in the furnace, the use of high top pressure has provided a further operating tool. In the use of this technique, the increase in density in the gas passing through the furnace should tend to reduce the amount of channelling and stock disturbance which takes place compared with operation at the same rate under normal conditions. For several years this technique was exploited by one Company only in the United States, but one British furnace has recently been so equipped and it is now reported that a number of other firms in the United States are making similar preparations. It is not yet very clear what operational advantages have been gained other than a considerable reduction in flue dust loss and, to some extent, the ability to maintain a high level of production under circumstances which would otherwise make fast working impossible. It is interesting to note, however, that the engineering developments associated with high top pressure operation have been of considerable benefit to blast furnace engineering generally, and a number of problems, mostly those associated with maintaining gas tightness on all parts of the furnace top, have been successfully solved. In addition, some of the equipment devised for the operation of bleeders and the maintenance of seating surfaces on parts of the furnace exposed to hot dusty gas could, with advantage, be incorporated in normal furnace construction.

Supervisory Staff

It is thus apparent that the modern blast-furnace plant together with its auxiliaries is tending to buy operational simplicity at the expense of mechanical and technical complexity. In the past, blast furnaces

3 Iron and Steel Institute Special Report 30.

4 *Journal of the Iron and Steel Institute*, **164**, p. 173 *et seq.*

frequently ran into the most spectacular kinds of operational difficulty, not so much due to lack of knowledge of the process as to lack of control over unpremeditated variations in operating conditions.

Consequently the type of man selected for the routine shift control of the plant was usually a man with many years of experience on the furnace front side who was capable of tackling such horrific items as breakouts, boils, chilled hearths, casting over the notch, jammed explosion doors and the like. Such men were usually extremely fine leaders of men and were at their best when the going was hard. Nevertheless, due to the circumstances of their training, it could hardly be expected that they would be able to keep up intellectually with some of the more complex technical developments which arose. In spite of this, however, many of them attained an astonishing mastery of the fundamentals of the process. However, in order to make the best of all the technical facilities available it soon became clear that use blast furnace staff must include a proportion of technically trained men, and in the recent past such personnel frequently had little or no responsibility for the routine operation of the furnace. There was a natural reluctance on the part of management to entrust the handling of the plant on shifts to people who, however brilliant their academic record, had comparatively little experience in the rough and arduous aspects of the work round the front side. As modernisation of plant continued, however, the more spectacular disasters of the past became less frequent and, even amongst the "practical" school of operator, the opportunities for learning by experience how to deal with such occurrences became increasingly rare. These circumstances tended to reduce the rather overwhelming advantage of years of front side experience. Nevertheless, it is abundantly clear that a technically trained man cannot make a successful operator until he has received his due quota of training and experience in working around the furnace. It is not given to many to have the right mental attitude to this type of work and there is a regrettable tendency amongst many younger technicians to regard furnace work, especially on rotating shifts, as somewhat undignified and demode compared with work on day shift in an advisory capacity. Such an attitude has retarded, to some extent, the development of the shift supervisor's job to the important and responsible status which it should rightly hold. Nevertheless, where perseverance in the face of wastage has resulted in the building up of strong teams of technical operators on the rotating shift, considerable benefits are obtained in unified methods of control and consistent response to managerial policy. It is certain that, as the general technical level of blast-furnace operation rises, so will the stress be laid more and more upon the need for the technical operator serving the plant throughout the 24 hours. This is not to say that the practical foreman risen from the ranks will no longer find a place in the industry: the need for his services will always exist, and it is a matter for finding the correct balance in staffing the plant between the two types of official.

Courtesy of Messrs. Stewarts and Lloyds, Ltd.

Fig. 5.—General view of the ore-bedding plant at Corby.

Conclusion

To summarise the foregoing, it appears that present trends in blast furnace practice exhibit the consolidation of much that has been learned in the laboratory and in the field during the past half century, resulting in plant consisting of large size units with great stress placed on facilities for the careful preparation of all materials for smelting, coupled with the necessary technical supervision to get the best results from all these facilities. Thus, blast-furnace practice is progressing steadily from an art to a science, but it would be a bold man who could say that the need for a skilled practitioner in the art could safely be disregarded, as no plant will operate forever without at some time running into difficulty where skill and hard-won experience will have to override nicer technical considerations.

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The Manufacture, Testing and Inspection of Turbine and Turbo-Alternator Rotors for Power Stations

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A number of interesting metallurgical problems arise in the manufacture of the large rotors required for the turbines and alternators of modern power generating plant. The range of operations, from the choice of the steel, through the ingot production, forging, and heat-treatment stages to the final inspection, is described in this article, and reference is made to some of the difficulties encountered.

THE problems encountered in the manufacture of these two types of rotor are in some ways similar and in others widely different. Both turbine and alternator rotors are required to be internally sound and as free as possible from internal stresses, and both are also required to have good and uniform mechanical properties from outside to centre—the actual level of these properties depending upon the dimensions of the rotor and its speed of rotation. The requirements are widely different, however, in the sense that a turbine rotor must be made from material which is suitable for service at temperatures substantially above atmospheric level, whereas an alternator rotor must have good magnetic and mechanical properties at ordinary atmospheric level, but the " heat resisting " properties of the steel employed are of no importance.

In deciding upon the most suitable methods of manufacture for a rotor forging, whether for a turbine or an alternator, it is customary for joint discussions to be arranged between the designer and the maker of the forging. As a result of these discussions, a specification is prepared, outlining the designer's requirements, such as mechanical and magnetic properties in the case of an alternator and mechanical properties at both normal and elevated temperatures in the case of a turbine. Such a specification also gives particulars of the testing and final inspection requirements which have to be carried out before acceptance of the forging for further processing at the designer's works. Many specifications contain a reference to the type of steel to be employed for the forging, but where some latitude is permissible, this is always given, leaving the choice of the exact range of composition to the manufacturer, who has the responsibility of ensuring that his material will satisfy the designer's specified requirements.

In the remainder of this article the various stages of manufacture of rotor forgings are discussed in the sequence in which they occur in practice. Though not strictly a manufacturing operation, some consideration is given first to the types of steel employed in rotor manufacture.

Types of Steel Used

For all the earlier types of rotor, a plain carbon steel was employed, since diameters and speed of rotation of the alternator rotors, and diameters, speeds and working temperatures of the turbine rotors, were insufficiently great to necessitate the use of alloy steel having superior mechanical properties. Furthermore, even when the demand for larger diameters and/or higher speeds became pressing, many designers were still reluctant to agree to the use of alloy steels, owing to the known greater susceptibility of such steels to internal defects, such as " snowflakes " or " hairline cracks," and comparatively external defects such as " ingot corner segregation." Much research and development work on the part of steelmakers and forgemasters was proceeding, however, side by side with designers' developments and, today, large numbers of rotors, both for turbines and alternators, are made in alloy steel to specification requirements greatly in excess of anything obtainable from plain carbon steel which, though still widely used, is limited to those rotors which are less severely stressed in service.

As has been stated earlier, the most important property of the material for a turbine rotor is ability to withstand the stresses developed at the designed speed and temperature and, it must be added, to maintain its dimensions under these conditions for long periods of time. One of the first, and perhaps still the most widely used, alloy steel for turbine rotors is 0·5% molybdenum steel, which is substantially better than plain carbon steel for service temperatures up to about 500° C. For conditions where still higher temperatures and stresses are involved, molybdenum-vanadium steel is being employed to an increasing extent, as it appears to be remarkably stable in properties over long periods of time, even at temperatures up to 550° C. For designs which involve high stresses, but somewhat lower temperatures, other alloy steels such as nickel-molybdenum, nickel-vanadium, nickel-chromium-molybdenum and 3% chromium-molybdenum, are now widely used, especially where the rotors are exceptionally large in diameter and where, in consequence, higher alloy contents are needed to ensure high mechanical properties at the centre of the rotor. For the most part, such highly alloyed steels do not operate at temperatures where " creep " is a serious problem, as would be the case at, say, 500° C., but for lower temperatures, such as are encountered in large " I.P." and " L.P." rotors, they have many advantages over the 0·5% molybdenum and molybdenum-vanadium steels which are superior in " creep " resistance and hence used for smaller rotors of the " H.P." type. At the present time, much research is proceeding in connection with steels to withstand still higher temperatures and stresses, even in rotors of large diameter, such as will be needed for the larger power installations of the near future.

The steels used for alternator rotors range in composition from plain carbon steel, which is used for purposes

where rotational speeds and/or body diameters are not large, to nickel, nickel-molybdenum, nickel-vanadium, nickel-chromium-molybdenum and, more recently, 3% chromium-molybdenum steels which are suitable for rotors of larger diameter, rotating at higher speeds. In British power station practice, rotor speeds are usually either 1,500 or 3,000 r.p.m. for a frequency of 50 cycles per second. At the former speed, a four-pole design is employed and at the latter, two-pole. Designs for these two speeds differ substantially, the slower speed rotors being of larger barrel diameter but shorter length for similar output. The corresponding specification requirements generally include higher mechanical properties for the 3,000 r.p.m. rotors and these are made, in consequence, in one of the four last-named steels already mentioned, the actual choice depending upon the minimum mechanical and magnetic properties demanded by the design in question. It should be emphasized, at this stage, that by employing suitable alloy steels it is possible to obtain a much higher combination of magnetic and mechanical properties than could be obtained by simply increasing the carbon content of plain carbon steels, since magnetic permeability falls off rapidly as the carbon content increases.

Steelmaking and Casting of the Ingot

The steel employed for rotor manufacture in this country is made by either the Acid Open Hearth or the Basic Electric Arc furnace process. Large rotors are made almost exclusively from Acid Open Hearth steel, since the capacity of the O.H. furnace is usually much greater and hence, larger ingots can be made without special ladle and casting pit arrangements. Another advantage of Acid Open Hearth steel is its somewhat lower average hydrogen content, which is associated with lower susceptibility to so-called " snowflakes " or " hairline cracks."

It is not possible here to deal more than briefly with steel making and ingot casting, but only the most carefully controlled methods should be used and casting temperatures and speeds should be adjusted so as to obtain maximum axial soundness in the ingot. For most rotor ingots, an ingot mould tapering substantially from top to bottom is highly desirable, since this shape promotes correct " feeding " of the ingot during solidification. The ladle nozzle size should be the smallest which can be relied upon to fill the mould without undue risk of " skull " and trapped non-metallic matter at the lower end of the ingot. By using small nozzles and, hence, relatively slow casting speeds, the freezing of the ingot from the bottom upwards is encouraged and axial soundness of the ingot is promoted. Slow casting speeds also have the advantage of preventing, or at least limiting, the serious defect usually known as " ingot corner segregation." If present to a serious extent, such segregation may lead to the rejection of a rotor forging, especially for an alternator, though these segregates are not generally dangerous unless they remain in the metal between the longitudinal slots. Unfortunately, different types of alloy steel exhibit differences in their tendency to skull formation and, consequently, what is a practicable pouring speed for, say, a nickel-vanadium steel may not be at all practicable for another steel containing more chromium. These differences in the permissible pouring speeds of different alloy steels are variously referred to as " fluidity," " condition " and, perhaps more logically, " castability," but it is extremely difficult to predict beforehand the exact degree of " castability " of any particular steel melt and much further investigation into this problem is being carried out.

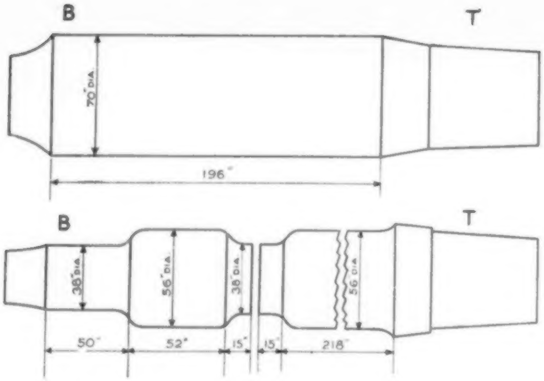
In general, it is desirable in making a rotor forging to select an ingot size so that the reduction of area from ingot to the largest diameter of the forging is round about $2\frac{1}{2} : 1$ minimum but, with the very large rotors which are now being designed, a smaller reduction is sometimes inevitable owing to the enormous size of ingot required. It is necessary also to select an ingot which will enable adequate top and bottom end discards to be made and the extent of these discards can only be worked out as a result of experience with ingots of a particular range of sizes in a particular composition.

Reheating and Forging

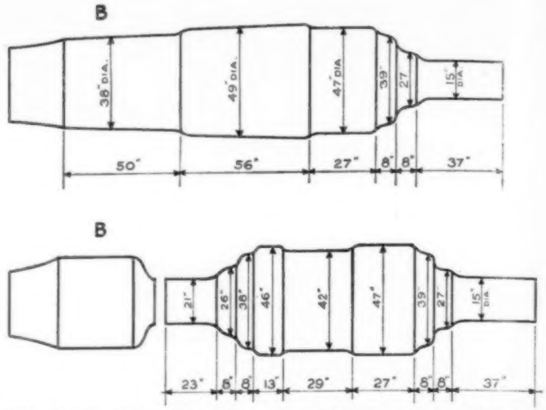
As a general rule, the safest practice to follow is to strip the ingot from the mould as soon as possible after complete solidification and transfer this hot ingot immediately to a forge reheating furnace. If, for some reason, the ingot has to be cooled down before forging commences, it is always carefully annealed before being allowed to go cold, the exact annealing cycle being dependent upon the composition of the alloy steel concerned. For example, there may be some surface defects in the ingot which require to be removed before forging can be completed and, in most cases, it is preferable to carry out a certain amount of forging before the defects are removed by, say, an oxy-acetylene torch. In steels having a composition particularly susceptible to ingot corner segregates, it has been found necessary at times to " cog " or rough forge the whole ingot to some convenient size larger than the finish forging size and then carry out an annealing treatment before rough turning the outside of the forging to remove the affected ingot corners. Obviously, in carrying out such an operation, it is an advantage to retain, in the rough forging, the same approximate shape as that of the original ingot so that what were original ingot corners will still be corners in the partly forged piece and thus enable these portions to be removed without too much loss of weight being involved. In all cases where such rectification of the exterior is required, it is very necessary that the forging should be reheated afterwards with care and uniformity in order to prevent the development of any internal defects due to substantial temperature difference.

A further precaution which is necessary in reheating an ingot to be forged into a rotor is that the heating should be as uniform as is possible, and it is often customary, especially with large pieces, to turn the ingot over in the reheating furnace at least once before withdrawing for the forging operation. An unevenly heated ingot will tend to produce an unsymmetrical forging and, as it is very necessary to ensure that the metallurgical axis of the ingot coincides as far as possible with the axis of the finished forging, serious consequences may result if these precautions are not taken.

Generally speaking, the maximum temperature of reheating for rotor forgings is about 1,200/1,250° C., depending to some extent upon the composition of the steel in question. With temperatures higher than this, there is a serious risk of at least local overheating. It is always necessary to ensure that the ingot is heated as uniformly as possible to the centre as, otherwise, the application of the press strokes may bring about rupture of the axial portion of the forging, which is inferior in



Figs. 1 (Upper) and 2 (Lower).—First and second stages of forging (" heats ") of alloy steel turbine rotor.



Figs. 3 (Upper) and 4 (Lower).—Third and fourth stages of forging (" heats ") of the same rotor.

plasticity if at a substantially lower temperature than the outside.

Two types of press are employed for making rotor forgings. The older, and perhaps more common, type being what is known as the " steam intensifier " press and the more recent, the " electro-hydraulic " press. Both probably have advantages of their own, but the chief merit of the latter type is that it allows deeper penetration to be effected at any given stroke of the press ram.

The stages of forging, generally with intermediate reheatings, differ considerably for different sizes and types of rotors, but a typical example is given in the case of a large turbine rotor in Figs. 1 to 4. Obviously, it would be impracticable to forge many of the modern designs of rotor strictly in accordance with the finished shape and where, for example, there are several different diameters involved, the shape as forged may be somewhat simplified in order to avoid unnecessary change of press tools and more numerous reheating operations.

It is necessary, at the forging stage, to make allowance for the material required for testing, both on the body and end portions of the rotor and these allowances are usually specified as accurately as possible in the forging drawing.

The importance of correct maximum temperature and adequate soaking has been emphasized earlier, but a further important precaution in the forging of rotors is that the temperature should not be allowed to fall too low during any given forging operation, otherwise the mechanical properties of the finished forging may be adversely affected. It is customary to stipulate, before forging commences, that no further forging work shall be carried out below some specified minimum temperature, which is generally in the region of 900° C., or even higher with some materials.

It will be seen from Figs. 3 and 4 that the two ends of a rotor forging are usually finished at separate heats and it is very necessary, when forging the last end, to make sure that the remaining portions of the rotor, which are not being worked, do not cool down to dangerously low temperatures during this last forging operation and, in particular, that they are not allowed to cool out completely, as was occasionally done, with disastrous results, when the manufacture of rotor forgings first commenced, many years ago.

Heat-treatment after Forging

This stage of rotor manufacture is one of the most critical, for it is upon the heat-treatment after forging that the presence or absence of such serious internal defects as clinks (major internal cracks) and the more insidious " snowflakes " or " hairline cracks " depends. Naturally, the exact heat-treatment cycle applied to the forging at this stage depends upon the types and amount of alloys present. Alloy steels which transform readily and completely in the pearlite range may be dealt with very satisfactorily by what is often called " isothermal " annealing, of which an example is given in diagrammatic form in Fig. 5. Other alloy steels, which require so long for complete transformation in the pearlite range as to make the process impracticable, are usually cooled down slowly through the intermediate transformation range, and held at some temperature known to be below this range for a sufficiently long time to ensure complete transformation to the centre. Whether the steel comes into the first or second category, however, the next part of the heat-treatment process usually consists of slow and uniform reheating to a temperature above the transformation range on heating and, when this temperature is judged to be uniform throughout the piece, the forging is cooled again at a controlled rate until transformation is complete, either in the pearlite or intermediate range as the case may be. The final stage consists of a further reheating to a temperature below the transformation range on heating, followed by adequate soaking at a selected temperature and, afterwards, slow cooling down to atmospheric temperature. Complete heat-treatment cycles of the two types just described are seen in Figs. 5 and 6, and it will be noticed that, in the case of steel which transforms readily in the pearlite range, the final reheating is omitted, as the steel should be already in its softest and most stress-free condition.

When the properties required from a rotor forging are such as to be attainable by a heat-treatment consisting of air cooling from the refining temperature, followed by tempering, the treatment after forging may be what might be termed a " combined precautionary and refining treatment " such as is illustrated in Fig. 6, but with the difference that the cooling after the refining at the second peak, shown in the diagram, is carried out in still air instead of in the furnace. During this more rapid cooling, the transformation in the pearlite range is

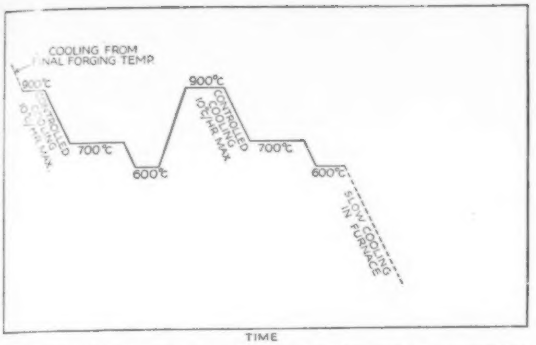


Fig. 5.—Diagram illustrating "Isothermal" annealing and refining treatment. The long holding periods at 700° C. are designed to effect transformation in the "Pearlite" range.

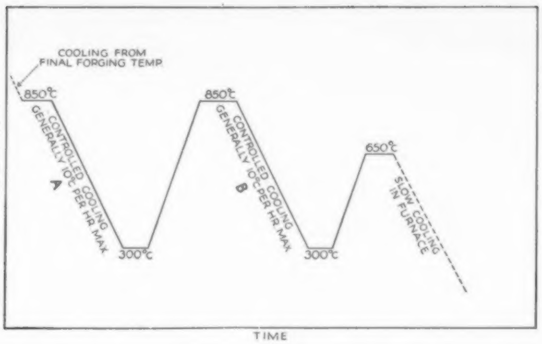


Fig. 6.—Diagram illustrating annealing and refining treatment which includes cooling through "Intermediate" transformation range at "A" and "B."

lowered and, with some alloy steels, eliminated, so that transformation only occurs in the intermediate or bainite range, say, roughly between 500° C. and 350° C. In other words, the steel is air hardened to an extent which depends upon the size of the rotor and the composition of the steel. The rest of the heat-treatment cycle remains as shown in Fig. 6. There are many advantages in effecting this combination and thus eliminating any further major heat-treatment after rough machining. Where the mechanical properties specified are very high, however, and the rotor forging is large, it is sometimes found necessary to employ an oil-hardening and tempering treatment in place of the more common air-hardening and, in such cases, the heat-treatment after forging is simply a combination of controlled cooling and annealing operations, the final properties being obtained only after the further heat-treatment described later in this article. It is perhaps unnecessary to point out that the oil-hardening of a large mass of alloy steel is not usually safe unless all surface imperfections have been removed by rough machining, which is always carried out where oil-hardening is involved, and is the next stage to be described.

Rough Machining

For alternator rotors, rough machining usually consists of turning down the barrel and shaft portions of the forging to within some pre-determined limits left on for final machining but, in the case of large turbine rotors in both carbon steel and steels such as 0·5% molybdenum and molybdenum-vanadium, it is desirable to rough "gash" the rotor at this stage, in order to ensure more effective cooling during final heat-treatment. It is important that no cold straightening of the rotor should be done prior to gashing, unless some further stabilising treatment is applied subsequently. If this precaution is not taken, rotors which have been cold straightened may distort appreciably when they are gashed, owing to the release of internal stress in the forging, brought about by the cold straightening operation. Where the steel employed is one with sufficiently deep hardening characteristics to permit a final heat-treatment to be carried out in the un-gashed condition, there are probably some substantial advantages in following this practice, since some of the small amount of internal stress left in the rotor at the end of the previously described heat-treatment is released simply through the gashing operation, and the remainder may be relieved by a further tempering described operation later in this article.

The important point here stressed is that the amount of rough machining carried out after annealing, but before final heat-treatment, may vary substantially with the different types of steel which are used for turbine rotors. Fig. 7 illustrates an example of a turbine rotor which was rough gashed before final heat-treatment.

So far, no mention has been made of the axial boring, which is an important part in the manufacture of most rotor forgings. Alternator rotors which are made from carbon and alloy steels suitable to give the desired properties after a normalising, or air-hardening and tempering treatment, are generally trepanned and smooth bored at what may be termed the "rough machining" stage in manufacture but, before trepanning, some preliminary testing is carried out to ascertain whether any re-treatment is required. On the other hand, turbine rotors which are to be gashed before final heat-treatment are not usually trepanned at this stage, because the tensile test from the trepanned core is the best possible indication of satisfactory properties in the axial region of the rotor and, hence, trepanning must be done after final heat-treatment. For the same reason, turbine rotors which are to receive a final full heat-treatment after rough machining, but before gashing, are not trepanned or bored until this heat-treatment is completed. Rotors in this last-mentioned category are subjected to the largest number of distinct stages of manufacture and actually undergo two separate rough machining operations, one following the precautionary annealing treatment and the other after hardening and tempering.

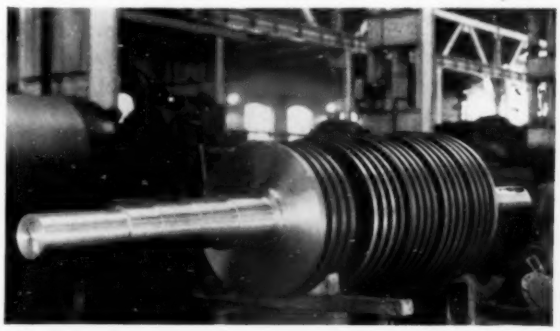


Fig. 7.—Turbine rotor to specification B.E.A.M.A. Grade III, rough gashed before final heat treatment.

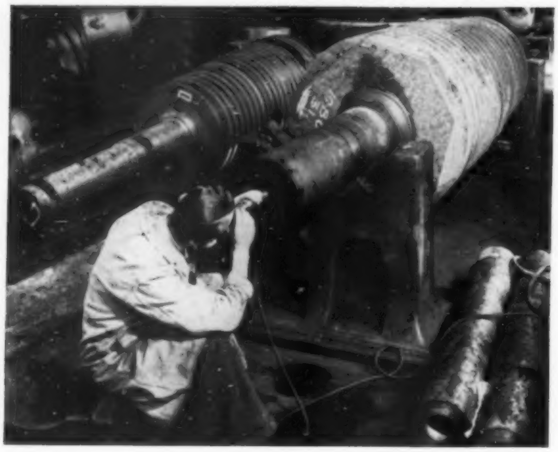


Fig. 8.—Boroscope examination of the magnetised bore of a turbine rotor made from steel of the 0·5% molybdenum type.

Review of Different Manufacturing Procedures Employed for Rotors

At this stage of the article, it may be helpful to review three different types of manufacturing procedure in common use, with the object of linking up the next sections dealing with final heat-treatment and inspection, with the previous sections describing the stages of manufacture up to rough machining. This necessity will be understood by examining the tables *a*, *b* and *c*, which illustrate the difference between rotors which receive their final heat-treatment before and after rough machining respectively :—

(*a*) Turbine or alternator rotor in carbon or alloy steel which receives its final heat-treatment before rough machining.

(*b*) Turbine rotor in carbon or alloy steel which receives its final heat-treatment after rough machining and rough gashing.

(*c*) Turbine rotor in alloy steel which receives a hardening and tempering treatment after rough machining, but before gashing and subsequent stress relieving treatment.

Type (*a*)

1. Forge.
2. Anneal and heat-treat as combined operation illustrated diagrammatically in Fig. 6.
3. Take preliminary tests from ends of body and shafts.
4. If satisfactory, rough machine and trepan.
5. Further mechanical testing if specified.
6. Boroscope, magnetic and supersonic inspection.

Type (*b*)

1. Forge.
2. Anneal as illustrated in Figs. 5 and 6, according to composition.
3. Rough machine and rough gash.
4. Normalise (or harden) and temper.
5. Take tests from specified positions.
6. If tests satisfactory, trepan and further machine.
7. Boroscope and magnetic inspection (in the case of a gashed rotor, supersonic examination is not usually required owing to ease of internal examination at the slot positions).

Type (*c*)

1. Forge.
2. Anneal as illustrated in Figs. 5 and 6, according to composition.
3. Rough machine.
4. Harden and temper.
5. Take preliminary tests.
6. If satisfactory, trepan and take core test.
7. If satisfactory, examine rotor body by supersonic method.
8. If satisfactory, rough gash and further machine.
9. Stabilise by reheating to a temperature somewhat below initial tempering temperature.
10. Take final tests.
11. If satisfactory, examine bore by boroscope and magnetic means.

Final Heat-treatment

From the preceding sequence of procedure for different types of rotor, it will be realised that rotors of type *a* have already received their final treatment as a part of the heat-treatment immediately after forging but in types *b* and *c*, the precautionary and final heat-treatments are carried out in quite separate stages. Final heat-treatment for categories *b* and *c* consists of cooling in air or, sometimes, in oil, from temperatures above the transformation range on heating for the steel in question, followed by tempering at a temperature which is known to bring the mechanical properties of the rotor within the specified range. In all cases, the heating of the rotor before hardening must be carefully and uniformly carried out, and the forging must be held at temperature for an adequate length of time to ensure maximum uniformity.

The tempering operation is specially important as, if properly carried out, there will be little or no internal stress left in the rotor at the end of this treatment. It is necessary, therefore, to give quite a long "soaking" period at the selected tempering temperature and, also, to ensure that cooling from this temperature, down to atmospheric level, is both slow and uniform. Generally speaking, it is an advantage to employ a tempering temperature as high as is permissible with any particular type of alloy steel, since both stress relief and all-round mechanical properties are better when the tempering temperature is high.

Testing and Inspection

As will have been gathered from the tables given earlier in this article for rotors of types *a* to *c*, testing may take place at more than one stage of manufacture, especially in the case of rotors of type *c*, where preliminary mechanical tests are taken to check satisfactory heat-treatment before the next machining operation is carried out. Inspection in one form or another may be said to start as soon as the ingot is cast, since the condition of the ingot surface before forging, and all stages of forging itself, are carefully observed and, according to what is revealed, some extra steps may be introduced into the manufacturing procedure in order to take care of abnormalities, such as ingot and forging defects, which it is desirable to remove before proceeding to a further

stage; in general, however, the following testing and inspection methods are applied to all rotors :—

Testing

1. Tangential and radial tensile test pieces are machined from one or both ends of the rotor body and longitudinal tensile test pieces from the ends of the shafts. If these tests are entirely in accordance with specification requirements, the rotor is carefully centred, and rough machining and trepanning are carried out in the case of rotors which are not to be subjected to a further stabilising treatment before trepanning. For example, such testing is only preliminary in the case of type *c* forgings because, with these, it is only after trepanning, and testing a portion of the trepanned core, that it is possible to say whether further heat-treatment is necessary.

2. If the forging is for an alternator, suitable pieces for magnetic testing are also removed from the ends of the barrel at this stage if the mechanical tests are satisfactory and these test pieces may be cut either tangentially or radially, according to the preference of the designer.

3. If the rotor forging is for a turbine, and some definite level of mechanical test is specified for the core, such a core test is likewise only preliminary at this stage if the rotor has been heat-treated " solid " and is to be subsequently gashed and retempered for stabilising before final testing.

Inspection

1. If not already examined in this way at the rough machining stage, bands are turned and polished on the periphery of the body of the rotor and, frequently, at the ends of the body, for examination by sulphur printing, which is valuable, especially in alloy steel rotors, as a method of determining whether ingot corner segregations are present.

2. After trepanning and smooth boring, the bore surface is critically examined by means of a boroscope and, if no visual defects are present, the bore is magnetised by means of a cable threaded through for the purpose and subsequently examined for cracks and flaws by spraying with so-called " magnetic ink." The bore is then re-examined by boroscope and careful note taken of the position and character of any small defects which may be revealed by the magnetic test, even though invisible beforehand. In carrying out this magnetic test, it is customary to spray the bore at least twice, since some " magnetic ink " generally collects in the lower portions of the bore when it is first applied and renders inspection of these portions difficult. The rotor is, therefore, turned through 180° to bring uppermost the portion which was the lower side during the first spraying operation. Any bore defects found during this process of examination are removed by re-boring and, sometimes, by " chambering " to whatever extent is permitted by the designer.

3. With alloy steel rotors, especially, it is customary at the present time to supplement the magnetic examination of the bore with a " supersonic " or " ultrasonic " test, in which a beam from an oscillating crystal is transmitted from the outside of the rotor body to the bore surface and back again to a second crystal, which is termed the " receiver." This apparatus would take too long to describe, but the principle involved is that any defect present between the point of transmission of the beam and the point of back reflection, which should be the surface of the bore, is shown on the trace provided by the cathode ray oscillograph as an echo intermediate between that resulting from the point of entry of the beam and the point of its reflection from the bore.

Fig. 9.—Testing for internal defects by means of the supersonic flaw detector.

This form of testing is extremely sensitive and requires great skill and experience, both in application and interpretation of the results. Its great value lies in the fact that it will reveal the presence of defects and abnormalities which are not accessible to inspection by any other known means.

Fig. 8 is a photograph showing the boroscope examination of a rotor after magnetisation of the bore, and Fig. 9 illustrates a test in progress by the supersonic apparatus (in this particular case, the forging is not a rotor, but the principle is precisely the same).

Heat Stabilisation Test

Though this test is probably superfluous when all manufacturing operations and, especially, heat-treatment have been carried out correctly, the designer's specification may include such a test in the case of turbine rotor forgings operating at fairly high steam temperatures, particularly if the forging in question is one of the gashed type used for impulse turbines, since these rotors are more liable to distort than those of the " solid " type employed for reaction type turbines.

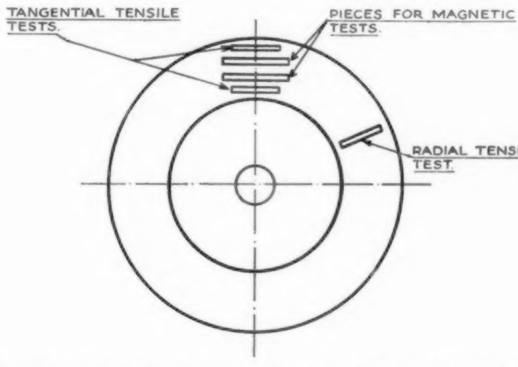


Fig. 10.—Diagram of position of test pieces taken from ends of rotor body.

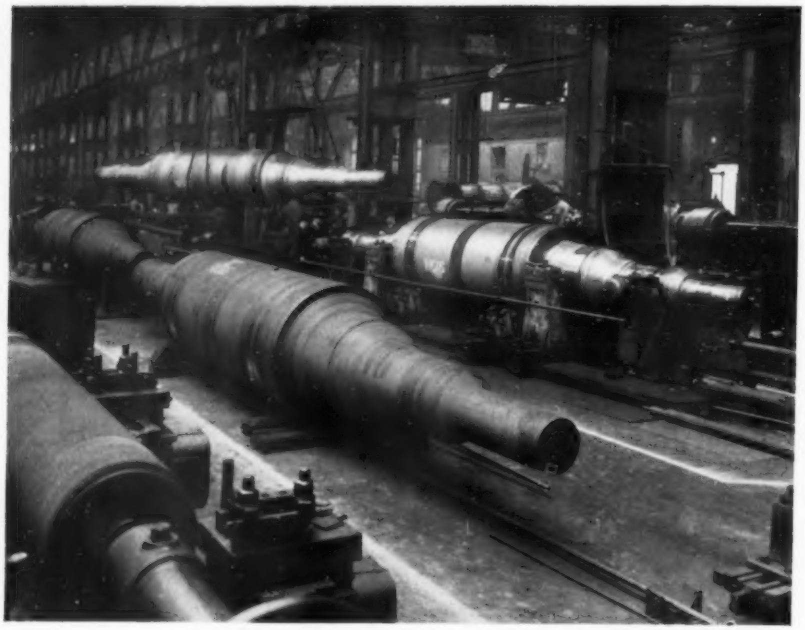


Fig. 11.—Four large alternator forgings made from 2% nickel steel.

The test consists of mounting the rotor, which has been accurately machined, both on the bearings and on two or more bands on the body portion, in suitable bearings (generally of the " V " type), so that it may be rotated inside a furnace whilst being heated up slowly to a temperature somewhat above the estimated service temperature of the turbine. If such a rotor is not free from internal stress, which may be caused either by faulty heat-treatment or by some unusually severe machining operation, distortion will occur during this heating and rotating process, so that the rotor runs eccentrically and, when slowly cooled again, may still be eccentric. Sensitive dial gauges, working in conjunction with lever systems, are employed to read the eccentricity of the rotor body at frequent intervals throughout the heating and cooling and a rotor is satisfactory if the difference between the final hot and the final cold reading is less than the specified maximum amount.

Naturally, such tests are not necessary in the case of alternator rotors, which are not subjected to temperatures appreciably above atmospheric level.

Examples of Actual Rotors Already Manufactured

The properties which have been obtained from actual turbine and alternator rotors are illustrated in the two examples which follow, No. 1 being a turbine rotor made in 3% chromium-molybdenum steel, to a procedure similar to example *c* given earlier in this article, and in shape, similar to the diagram, Fig. 4, but with the black surface removed by machining.

No. 2 is an alternator rotor in nickel-vanadium steel having the following approximate dimensions :—

Body diameter 36 in. : Body length 111 in. :

Overall length 270 in.

The position of the test pieces on the body ends of this rotor are illustrated in Fig. 10, which also serves to illustrate the arrangement of such tests in general, though for most specifications, fewer test pieces are required. This particular illustration is given here as an example of remarkable uniformity in properties sometimes attained in a rotor forging of this size. The heat-treatment, after forging, was of the combined precautionary and refining type mentioned earlier, but a double refining was employed at temperatures of 900° C. and 820° C. respectively.

EXAMPLE No. 1

	Y.P. tons/sq.inch.	U.T.S.	El. %	R.A. %
T.X.	36·7	49·7	13·0	24·8
B.X.	36·4	47·5	15·5	42·6
T.L.	36·3	47·8	16·3	65·1
B.L.	35·2	46·7	17·4	66·6
Core (mid)	36·9	47·6	11·6	43·5

Note.—In this, and Example No. 2, " TX " signifies transverse from top end of body and " BX " transverse from bottom end of body, whilst " TL " and " BL " signify longitudinal from top and bottom ends of the shafts respectively.

It should be noted that, in the case of Example No. 1, the test piece used was a Continental type and hence the ductility figures are substantially lower than for a British test piece.

EXAMPLE No. 2

	Y.P. tons/sq.inch.	U.T.S.	El. %	R.A. %
T.X.	31·5	44·5	17·0	29·1 (outside)
T.X.	31·5	44·0	15·0	26·0 (inside)
B.X.	29·0	44·0	17·0	29·4 (outside)
B.X.	29·0	44·5	20·0	32·7 (inside)
B.L.	31·5	44·6	23·0	56·4
B.R.	29·0	44·0	16·0	26·0
T.R.	29·0	44·0	16·0	26·0
Core (mid)	27·0	42·0	26·0	52·2

" T.R." and " B.R." signify radial tests from top and bottom ends of the body respectively.

To give an idea of the size and shape of some alternator rotor forgings, Fig. 11 is an actual photograph of four such forgings in a heavy machine shop. The rotor in the background to the right is in process of being smooth bored and the core piece previously trepanned from this same rotor can be seen in front of the boring machine, supported on two brackets. A further core piece is lying on the floor in the right foreground of the picture.

Uneven Hardness Gradients in Quenched Steels

By Hugh O'Neill, M.Met., D.Sc., F.I.M.

Professor of Metallurgy in the University College of Swansea

Jominy hardenability curves occasionally show an unusual rise or hump and similar effects have been found in hardness surveys of welded joints and in steel rails which have had a special " hardening " treatment applied to the head. It is suggested that the original austenite transforms locally in the intermediate range.

IN the Jominy test for hardenability of a steel, the lower end of a red hot cylindrical specimen is water-quenched under standard conditions until the whole bar is cold. Diamond hardness tests are then made upon specially prepared flats running from end to end of the 4 in. bar, and a graph of hardness against the distance from the quenched end is known as the Jominy hardenability curve. For a eutectoid steel this curve falls smoothly from a high value at the rapidly quenched end to a Vickers hardness of say 350 at a distance of 3 in.

In the Report of the Symposium on Hardenability[1] Figs. 32 and 339 gave results for steels containing about 1% chromium where the hardenability curve showed an unusual rise or " hump " of 25–50 Kg/sq.mm. at about 1·5 in. along the bar. In a written contribution to the Discussion the present writer[2] recorded that he had previously found a similar slight hump when medium manganese rail steels were given certain quenching treatments, and that the presence of notable amounts of chromium was not necessary to produce the effect. He pointed out that a hump was also present, for instance, in Figs. 77 (Steel 65, 1·95% Si, 1·03% Mn) and 70 (Steel 9, 0·28% C, 1·60% Mn). The present article gives particulars of some observations obtained on rail steels containing about 1% of manganese.

Incidentally Jominy tests on rail steels have been published[5], but the absence of hardness determinations at distances between 1 and 2 in. along the bar may explain why no secondary hump was observed.

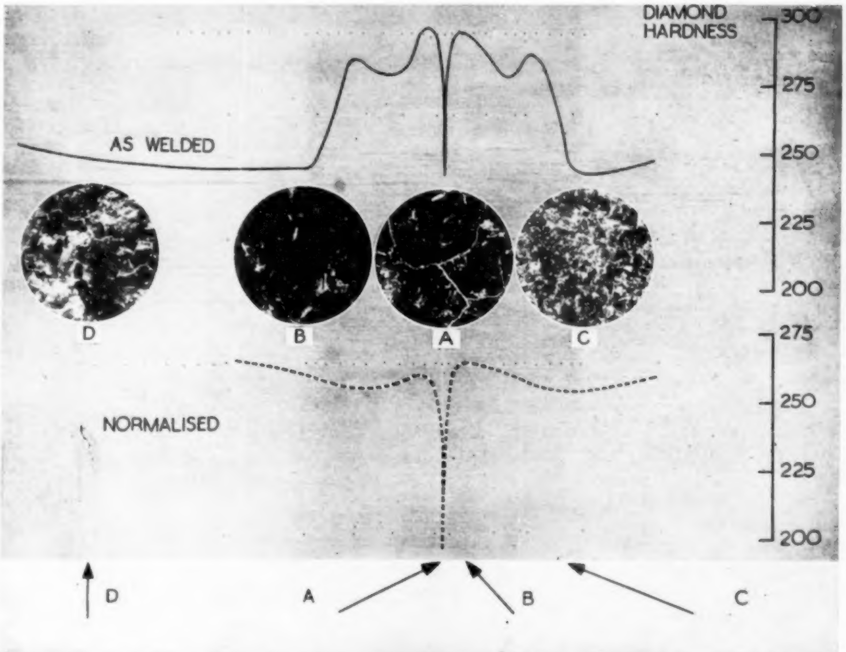


Fig. 1.—Hardness exploration and structure of flashbutt-welded rail.

Effects in Flash Welding

During 1936, electric flashbutt welding was carried out on an A.E.G. machine with 95 lb./yd. bullhead rails of the following percentage composition :—

C	Mn	Cr	N
0·66	1·02	0·13	0·008

During the preliminary arcing and flashing, the two ends to be welded reach a high temperature, and after the final upsetting the red-hot weld cools in air. The cold portions of the rails act as heat sinks, and so from the hot plane of welding to the free end of the welded bar, we have conditions somewhat comparable in principle to those of the Jominy test.

One of the rail welds was sectioned longitudinally and explored for hardness distribution after etching. The results obtained in 1936 are illustrated in macrograph Fig. 1, and were described in a 1944 paper[3] as follows : " Immediately adjacent to the soft zone (in the plane of welding) was a twin peak of maximum hardness which dropped away to a zone of annealed steel having a somewhat lower hardness value than the original parent rail." In other words, this curve fell from 290 Kg/sq.

1 Iron and Steel Inst., Special Report No. 36, 1946.
2 Iron and Steel Inst., 1947, **157**, 76.

3 N. W. Swinnerton and H. O'Neill, *Trans. Inst. Welding*, 1944, 7, 1.

mm. and showed a hump of about 8 Kg/sq.mm. at approximately 1·6 in. distance away from the hot plane of welding. At about 2·5 in. the dark-etching zone of heat transformation ended, and at this position the steel was actually softer than its initial value of 250 Kg/sq.mm. The slight "sump" was associated with the presence locally of a spheroidal type of pearlite.

In this connection it may be remarked that Fig. 368 in the Hardenability Symposium represents the Jominy curve for a hyper-eutectoid chrome-molybdenum steel which appears to show a minimum hardness value or sump at about 1·5 in. from the quenched end. Many published results suggest hardness minima near the edge of a heat transformed zone.

Available hardness surveys of flash welds have been scrutinised and it is not infrequent to find twin hardness peaks on one side of the plane of welding. Even the narrow transformed zone alongside a metallic electrode weld in a rail showed first, "the Widmanstatten structure of tempered martensite" (H_D 420 approx.) and then a harder zone described as "upper bainite" (H_D 440 approx.)[4]. Hardness traverses of the transformed region of metallic arc welds in alloy steels frequently show humps and sumps.

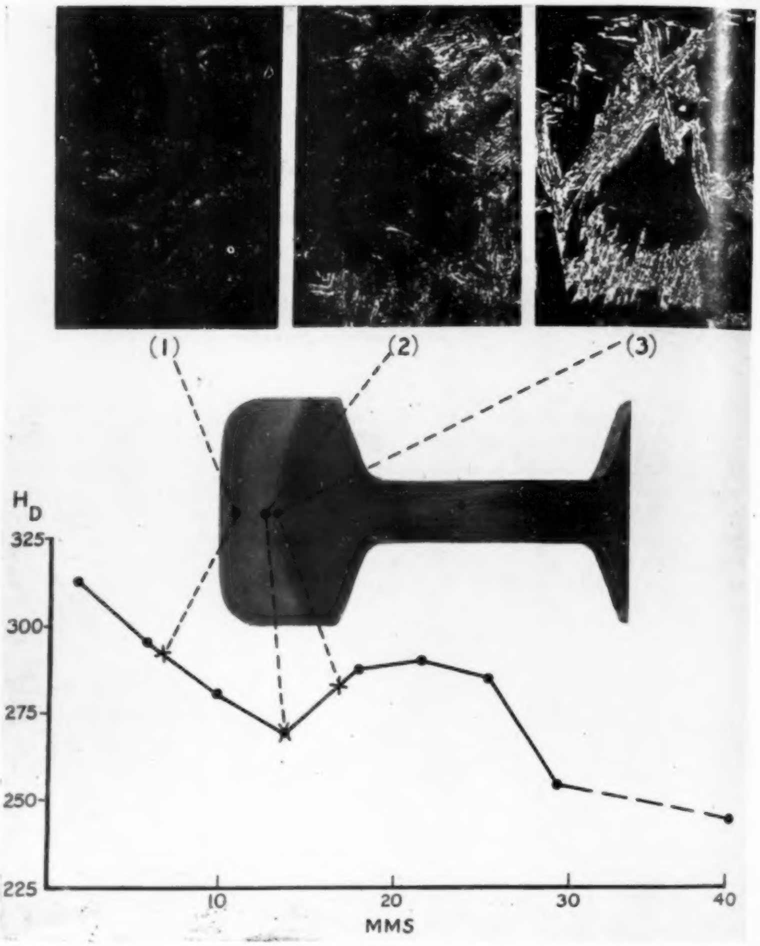


Fig. 2.—Hardness exploration and structure of a "sorbitised" rail head.

Sandberg Sorbitised Rails

The running surface of a rail may be treated by the Sandberg process so that its Brinell hardness number is raised from about 220 to 330. The process consists of allowing the red hot rail from the rolling mill to run under a quenching hood, where a very fine mist of cold water is deflected on to the top surface for a controlled time. The rate of quenching is low, and whilst most of the rail remains red hot for a considerable time, the top surface is black on leaving the hood. A vertical element of the rail may be considered as having undergone a partial Jominy quench.

Vickers hardness tests down the centre line of a transverse section of a typical specimen show a fall from 330 at the running surface to 250 towards the web of the rail. The gradient is generally considered to be smooth, but the writer has found hump effects in some rails. In one published example[5], a rise from 275 to 290 occurred at a distance of about 0·7 in. below the quenched surface. The composition of the steel was C 0·53%, Mn 1·18% and Si 0·15% but the micro-structure was not examined in detail at the time.

In 1946 an opportunity arose to study a new sorbitised rail of composition C 0·51%, Mn 1·16%. The results obtained are given in Fig. 2, and the hardness gradient again shows a hump of about 20 Kg/sq.mm. at 0·8 in. below the quenched running surface. The reality of the hump was confirmed by normalising the specimen at 850° C., whereupon the hardness graph when deducted from that first obtained still gave a hump. The microstructures at various positions may be described as follows :—

Location	Diamond hardness	Microstructure
Position 1 (Distance 6 mm.)	297	Dark etching zone, resolvable as a background of sorbite overlaid with broad black interlacing needles. "Acicular sorbite."
Position 2 (Distance 14 mm.)	272	Non-acicular pearlite type structure mixed with dark sorbitic areas.
Position 3 (Distance 20 mm.)	292	Acicular intermediate product mixed with dark sorbitic background.
Position 4 (Distance 30 mm.)	256	Ferrite and pearlite.

It appears from the microstructures that the presence of 1% manganese, together with the series of cooling velocities during Sandberg treatment, has enabled some of the original austenite to transform in the so-called "intermediate" range. The work of Griffiths, Pfeil & Allen[6] shows that the presence of the intermediate

4 W. J. Leonard, *Welding Journal Res. Sup.*, 1949, Aug. 14.
5 H. O'Neill, *Inst. Civil Engrs.*, 1944-45, Railway Eng. Div.

6 Iron and Steel Inst., Special Report 24, 1939.

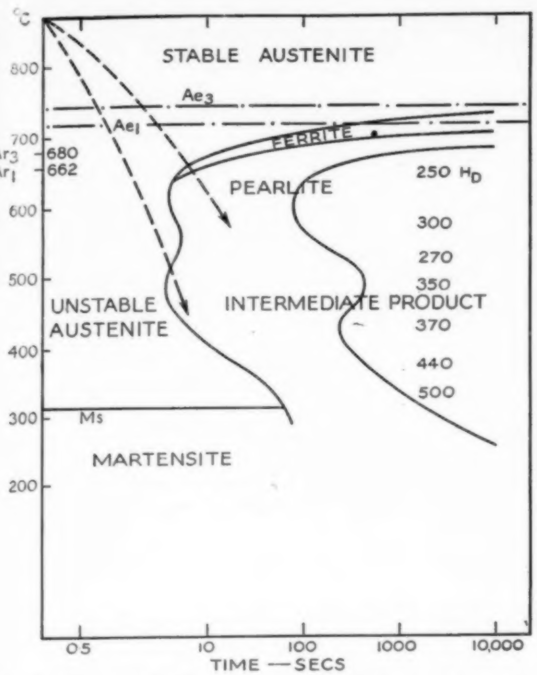


Fig. 3.—Suggested isothermal transformation diagram for a 0·55% C., 1·1% Mn steel.

product leads to "a moderate increase in strength," which is consistent with the hardness hump.

End-hardened Rails

In 1944 the present writer recorded[5] details of a process for hardening the ends of rails in the track to 400 D.P.H. by heating to redness, and then applying a limited amount of water to the running surface. Hardness tests on a longitudinal section through the centre line of a rail (C 0·59%, Mn 1·20%) treated in this way showed a subcutaneous "soft" zone of about 320 D.P.H. preceding a hump zone of 360 D.P.H. beneath it. Acicular structures were reported at the time but were not studied in detail. A similar effect was described by Cramer in 1940, when discussing a paper on "Time Quenching" by Burns and Brown[7], but no detailed explanation was given. It is now suggested that the unevenness is due to the incidence of the intermediate transformation as in the other examples mentioned earlier.

Relation to TTT Diagram

An up-to-date isothermal transformation diagram for a medium manganese rail steel is not available, but a combination of the results for 0·64% C. and 1·13% Mn given in the U.S.S. Atlas (1943) with those for En15 and En45 published in the Transformation Atlas of the Iron and Steel Institute (1949) implies the outline sketched in Fig. 3. The derived diagram for specimens undergoing continuous cooling as distinct from isothermal change will resemble it in form. Pumphrey[8] has shown how this shape of diagram and various rates of cooling correspond with the hardness hump which forms on the Jominy curve of certain chromium steels, and at the position of the hump the structures contain intermediate products resembling those in the sorbitised rail. For manganese steels, the arguments of Wever and Mathieu[9] may apply.

In the Transformation Atlas, the hardness values for silico-manganese steel, En45, on completion of isothermal transformation at various temperatures are as follows :—

Isothermal temp.° C.	400	450	500	550	600	700
H_D	382	313	309	326	298	268

A hump is here in evidence at 550° C. due to the intermediate type of transformation.

It is generally considered[6] that the presence of intermediate product is associated with inferior notch impact values. To this extent it might be preferable to sorbitise plain carbon rather than medium manganese rails, as the former have a simpler transformation diagram. The question is not important, however, for in any case rails only have an Izod value of about 5 ft. lb.

The experimental data used in this article was obtained in the L.M.S. Railway Research Laboratory, Derby, and the material is published by courtesy of the Railway Executive.

7 *Trans. Am. Soc. Metals*, 1940, March, 28.
8 *J. Iron and Steel Inst.*, 1947, **157**, 27.
9 *Mitt. K.W.I. Eisenforsh.*, 1940, **22**, 9.

The Festival Star

A Festival of Britain feature which is attracting a good deal of attention is the huge magnesium star 50 ft. above the roadway in Northumberland Avenue.

One of the most ambitious structures ever to be attempted in magnesium alloy, it was constructed by

Essex Aero, Ltd., of Gravesend. A number of manufacturing difficulties had to be overcome as a result of the design requirements. A glued sandwich construction (16 gauge outer skin and 20 gauge inner skin with Welsh hat type of fillers) was used for the main panels and the maximum size of sheet available involved the butt welding of the outer skins, followed by very careful fettling of the weld to give an uninterrupted surface.

Institute of British Foundrymen

Annual Conference at Newcastle-on-Tyne

PRECEDED by Council and Committee meetings on June 12th and later on the same day by a Reception and Dance, by invitation of the Lord Mayor and Lady Mayoress of Newcastle-on-Tyne, on behalf of the City Council, the 48th Annual Conference of the Institute of British Foundrymen was held at Newcastle-on-Tyne from June 13th to 15th inclusive. Nearly 600 members and ladies participated in the various sections of the Conference. It was the first occasion since 1924, when the late Mr. R. O. Patterson was installed President, that the Conference had been held in Newcastle-on-Tyne, and in consequence considerable local enthusiasm prevailed.

The Annual General Meeting was held on the morning of June 13th, in the lecture theatre of the Literary and Philosophical Society, Mr. John J. Sheehan, B.Sc., F.I.M., presiding, at which the minutes of the previous meeting were taken as read, as also was the Annual Report of Council for the session 1950–51. The balance sheet and statement of accounts for the year ended December 31st, 1950, were adopted. The Annual Report of the Technical Council, in the unavoidable absence of the Chairman, Mr. A. E. Peace, was presented by Dr. A. B. Everest who referred with regret to the resignation of Mr. L. W. Bolton, who had rendered valuable services as Vice-Chairman for many years, owing to very heavy business commitments. Five Sub-Committees of this Council are now functioning and reports of three of them were presented at the technical sessions of the present Conference.

1951 Awards

At a Council meeting, previously held in Birmingham, resolutions were adopted for the medal awards for 1951, and the presentations were made at this meeting. In presenting the E. J. Fox Medal to Mr. H. Morrogh, in recognition of his pioneer work on nodular cast iron, and of his important contributions to research on cast iron over a period of years, Mr. Sheehan said that of fifteen major contributions to the development of cast iron, thirteen of them originated in this country, and it was a great pleasure to recognise the great pioneer work of Mr. Morrogh in this way.

Calling upon Mr. Barrington Hooper to make the presentation of the British Foundry Medal and Prize of £10 to Mr. E. S. Renshaw and Mr. S. J. Sargood, respectively, the chairman said that the award was made for their joint authorship of the paper entitled " Some Modifications in Cupola Design " published in the recent volume of the proceedings of the Institute. The presentation of the Meritorious Services Medal was made to Mr. A. S. Worcester in recognition of his valuable services to the Institute in many capacities over a long period of years.

Apart from Mr. Worcester, who was not present, the recipients appropriately replied.

Award of Diplomas

The Council, as a result of recommendations from various Branches, awarded diplomas for papers read before Branches, during the past session, to the following authors :—

Mr. G. E. Fearfield for the paper " Core Blower Application and Operation," read before the East Midlands and Lancashire Branches ; Mr. K. H. Wright for the paper " Chill Roll Manufacture " read before the Birmingham Branch ; Mr. D. Redfern for the paper " Loam and Dry-sand Moulding in the Jobbing Foundry," read before the Lancashire Branch ; Dr. E. Scheuer for the paper " History and Development of Aluminium Silicon Alloys," and Mr. M. M. Hallett for the paper " Practical Experiences in Producing Nodular Cast Iron," read before the London Branch ; Mr. J. Currie for the paper " Intricate Castings from a Durable Loam Mould," read before the Scottish Branch.

Election of Officers

Mr. Colin Gresty was elected President for the year 1951–52 and was invested with the chain of office by the retiring President, Mr. Sheehan. Dr. C. J. Dadswell and Mr. E. Longden were elected senior and junior Vice-Presidents, respectively. The following members were elected Members of Council, to serve for two years : Mr. L. W. Bolton, Mr. N. Charlton, Mr. V. Delport, Mr. P. A. Russell and Mr. G. R. Shotton.

Presidential Address

For his Presidential Address, Mr. Gresty, who joined the Institute 34 years ago, found the choice of subject by no means easy, probably because every aspect of foundrywork has been covered to some extent by previous Addresses. He proposed, however, to deal with certain matters of outstanding importance in the industry today. He was impressed recently by remarks made by one of his firm's loam moulders on receiving a presentation after 55 years' service. That old moulder said that foundrywork was a grand craft and that if he had to start life again, he would not wish to make any change ; moreover, that after more than 50 years' practical work he was still learning. In those few words, said the President, that man expressed two fundamental truths about foundrywork : (1) that it is indeed a grand craft and (2) that even a lifetime is not long enough to master all its problems.

This intense pride of craft, which still imbues many of the older craftsmen, is, unfortunately, not so evident in the younger men of today. There are, no doubt, many reasons why this is so, the principal one being the economic effects of two major wars during the last 37 years. It is, however, a matter greatly to be deplored, because this pride of craft, this satisfaction in a difficult job well done, has a very high moral value in urging a man to give his best under all circumstances. It is the best of incentives because it satisfies something in man's make-up that cannot be matched in its effect by incentives of a purely material character.

The President looked upon this Institute as the most powerful influence today for the encouragement and development of pride of craft, provided that it continues its policy of building up its membership from *all* grades of foundry workers. He was referring not only to moulders and coremakers, but broadly to all those skilled people—patternmakers, metallurgists, engineers—who

are part of the industry and who, by their joint efforts, have brought about much progress. Thus, the skill of the patternmaker is no longer confined to wood patterns, but, coupled with that of the foundry engineer, has rendered possible the mass production of intricate castings by methods mainly of a mechanical character. The skill of the metallurgist in applying science in the foundry, and in assisting in developing the production technique of special processes has resulted in new casting alloys, for many purposes, possessing improved properties in comparison with older metals and alloys. At the beginning of the 1914–18 war, for instance, The British Admiralty Specification for cast iron called for a minimum tensile strength of 9 tons/sq. in. During the war this requirement was raised to 11 tons/sq. in. for certain castings, as a result of which there was considerable perturbation in foundry circles. Today cast irons in the range up to and even exceeding 40 tons/sq. in. tensile strength can be produced. Phenomenal developments have also been made in the light casting industry, whereby the demand for the production of large numbers of intricate castings has been met. A record of great progress in the development and production of steel castings is not less imposing, particularly alloy steel castings for corrosion-, heat- and wear-resisting purposes. For some high-duty applications, particularly turbine blades and other parts for gas turbines, certain nickel-chrome and cobalt-chrome alloys have been developed and, in some cases, coupled with the refined technique of precision investment casting—a modern adaptation of the "lost wax" process. Added to this record of progress is the fact that, notwithstanding the present shortage of skilled labour, the total production of castings is at a very high level, probably higher than ever.

Taking into consideration all the factors outlined by the President, it is most unfortunate that, particularly during the last few years, the industry has been subjected to exaggerated propaganda about its working conditions. The chief result of this propaganda, and one which has had a disastrous effect on recruiting, is that the popular idea today is that a foundry is not a good place in which to work, instead of being known as a place where astonishingly clever things are done and where craftsmanship of a high order is needed. It is the opinion of the President that the industry has a great deal more of which to be proud than of which to be ashamed. In expressing this opinion, however, he did not wish to be misunderstood. For some years he has been closely connected with the subject of improving working conditions, and is fully aware of its importance ; he is well aware also, however, that some of the major problems in this connection are very difficult to solve and call for much research and experimental work. It is necessary, therefore, to keep a proper sense of proportion in these matters, and never to lose sight of the fact that the prime function of the foundry is to produce usable castings.

A notably large section of the 1949 Report of the Chief Inspector of Factories is devoted to foundries and the industry receives credit for considerable progress made in certain directions, such as provision of washing facilities, clothing accommodation, improved lighting and other matters. This progress, said the President, has been continued and extended in 1950, but it will be appreciated that improvements of this kind are comparatively straightforward, depending largely on funds and space being available to carry them out. The Report draws attention to the more difficult and complex problems of ventilation and means of suppressing dust, fumes and smoke, and refers in particular to the absence of reliable data for the designing of ventilating equipment. Progress in this direction is inevitably slow because of the need for research and experimental work. The importance attached to this subject by the Institute is indicated by the fact that two papers on the subject of dust were presented in one of the technical sessions at the Conference, one of which included a film on dust flow. These papers describe new techniques which have been developed and which are likely to become increasingly applied to the investigation of dust problems.

The President referred to the various Committees working on the closely related subjects of the suppression and removal of dust, smoke and fumes, all of which require facilities for carrying out investigational work in foundries and for carrying out new ideas. In addition, there is ample scope for individual thought and experiment in trying to solve some of the many interesting and intricate problems which exist in every foundry and he especially asked those who had been successful in curing any of their troubles to make their methods known, so that others may be helped.

In his concluding remarks the President returned to his main thought that foundrywork should not be decried—it is a grand craft in the broadest sense of the term, has a fine record of progress and the industry is taking very active steps in an endeavour to solve the difficult problems relating to the improvement of working conditions.

Edward Williams' Lecture

There was a short break following Mr. Gresty's Presidential Address, after which a large and appreciative audience assembled to listen to Dr. R. W. Bailey, F.R.S., deliver the 1951 Edward Williams' Lecture on the subject "The Properties of Materials and the Engineering Uses of Cast Metals." Dr. Bailey served an apprenticeship to mechanical engineering and has a very wide practical and scientific experience. In his earlier years he was a lecturer in mechanical engineering, and for seven years he was Principal of a Technical Institute ; in 1919, however, he took charge of the mechanical engineering and chemical laboratories of what is now the Metropolitan-Vickers Electrical Co., Ltd., and later also the metallurgical laboratory in the Company's research department, where as one of his duties he carried responsibility for all high-duty castings and forgings. During many years he devoted attention to mechanical engineering problems concerned with the strength and design of important parts of power plant, giving particular attention to the behaviour and operation of metals at elevated temperatures and high stresses. Important advances in the use of special steels for steam and gas turbines have resulted from his own work and that of the research section under his control. In 1945 he relinquished administrative duties to permit him to give greater attention to special problems concerned in power plant development by the Company for high operating temperatures, and to act as a consultant to the Company. He has had many honours conferred upon him. A slightly abridged form of his lecture is presented elsewhere in this issue.

Social Events

In addition to the Reception and Dance, previously referred to, the social arrangements were of a very high

order. Of these particular mention can be made of the Annual Banquet at the Old Assembly Rooms on the evening of June 13th, which followed the Reception by the President and Mrs. Gresty. Some 500 guests, members and ladies participated in what was acclaimed by all as a most enjoyable evening. On the following evening an Informal Social was held at which excellent entertainment was provided. Special mention should also be made of the Dinner-Dance at the Old Assembly Rooms which provided a fitting conclusion to a very successful Conference, and the Officials, Council and the various Committees responsible are certainly to be congratulated for maintaining such a high standard.

Technical Sessions

Six technical sessions were held at which fourteen papers were presented, together with three reports from Sub-Committees of the Technical Council. Because of the limited time, two sessions were held simultaneously, during the afternoon of June 13th, and during the morning and afternoon of the following day. The subjects presented for discussion covered a wide range, and considerable attention was given to practical aspects. The attendance of members at many of the sessions was particularly high, and, owing to the limited time available, some members were asked to submit their contributions to the discussion in writing. Here it is only possible to give a very brief summary of the subjects presented and discussed.

Heat Transfer in the Foundry

From early days in history founding has been an art, but in the last few decades science has gradually been applied with very considerable success in the production of castings, but whether the application of science to this industry will displace the art of the craftsman is extremely doubtful. However, it is claimed that to meet the competition of other means of providing complex shapes, progress in the founding industry is needed, and progress involves a critical review of many aspects concerned with production. One of these aspects, that dealing with thermal considerations in foundrywork, is discussed by Dr. Victor Paschkis in an exchange paper from the American Foundrymen's Society, which was presented at the meeting by Mr. J. F. B. Jackson. The author suggests that in modern industry, results can be obtained only by team work and co-operation between many specialists, one of whom, in foundrywork, should be a heat-transfer expert. He discusses fundamentals of heat transfer, surveys the heat problems in the foundry, and some methods of making thermal studies. In connection with the latter he describes a method which has been developed following about seven years of intensive study of the subject. For unknown reasons, the author states, the flow of heat by conduction in bodies and the flow of electricity in bodies with evenly distributed resistance and capacitance follows the same mathematical laws and on this basis an instrument, referred to as an Analogue Computer, has been developed. For complex conditions, such as in casting work, it is not possible to solve the mathematical equations of the equivalent electric circuit, but it is claimed that, if the analogous electrical process is carried out, nature provides the solution for foundrymen, and by measuring the electrical values they can obtain the solution of the analogous thermal problem. Some details of the technique are shown in an Appendix, but the subsequent discussion centred on the application of the technique in the foundry.

Temperature Measurement

The French exchange paper from the Association Technique de Fonderie, by M. Marcel Chaussain, was presented by Dr. A. B. Everest, and deals with platinum and platinum-rhodium thermocouples and their industrial applications. The author surveys methods of testing and inspection of thermocouple wire, and shows that progressive development of industrial pyrometry has led to a method of calibration by a standard reference curve, enabling the Pt : Pt-Rh thermocouple to be used for temperatures up to 1,720° C. It is emphasised that, for interchangeability, the thermocouple wires should be of special quality and their characteristics defined by appropriate standards. The works laboratory should test thermocouple wires and supervise their behaviour in service. The most suitable test method is stated to be that of differential comparison with reference standards, which is both a method of control and of experimental technique, and is capable of furnishing valuable information and considerably increasing knowledge of thermoelectric phenomena. A particular testing technique is described which has enabled the degree of ageing of thermocouple wires to be measured in various contaminating media, with the result that thorium oxide has been found to afford the best protection against contamination of thermocouple wires. Used for temperature measurements in steel baths, thorium oxide shielding has proved to be a method enabling very accurate and reliable values to be obtained with the instruments normally used in thermo-electric pyrometry. Pyrometer rods have been devised for measuring steel bath temperatures in high-frequency, arc, and open-hearth furnaces, providing a simple and inexpensive solution for the problem of correct temperature determination in industrial steel furnaces.

Solubility of Carbon in Cast Iron

Details of an investigation into factors governing the solubility of carbon in cast iron are given in a paper by Dr. R. V. Riley. The experiments were carried out in laboratory furnaces under carefully controlled conditions. Carbon solubility in iron was determined in selected atmospheres of hydrogen, oxygen, nitrogen and air, at normal and low pressures, and in vacuo. The work has shown that available knowledge upon the form of the liquidus of iron-carbon alloys containing over 4·5% carbon is incomplete. Carbon solution rates in high-carbon cast iron are in conformity with the general laws relating to the solution of a solid in a liquid. The rate of solution depends upon (1) temperature of the molten iron; (2) concentration of carbon in iron; (3) mixing of the carbon with the molten iron; (4) nature of the carbonaceous materials and surface characteristics; and (5) the presence of agents which may interfere with or assist carbon solution. The ambient temperature has an important indirect effect upon carbon solubility rates. The author shows that the normal cupola atmosphere is not conducive to the production of high-carbon iron. Calcium carbide additions have specific action in raising the carbon content of cupola melted iron.

Patternmaking

Mr. B. Levy presented a practical paper giving some present-day practices in patternmaking, the primary

objects being to show the application to the job of materials, methods and machinery, special references being made to the impact of the latest innovations to the patternshop on actual workshop practice. Among the duties of the patternshop supervisor is that of establishing liaison between foundry, drawing office and machine shop, and resulting from this consultation the author details seven factors, a careful consideration of which will determine the type and character of the appropriate pattern equipment, nine types being given from which a choice of any one, or a combination of two or more may be made for any given job. It is noteworthy, as the author points out, that strickle boards and skeleton patterns still occupy an important place in the economic production of many types of castings, although he states that much loam and strickle work has been replaced by the employment of full wooden pattern equipment. A 10 ft. diameter sheave wheel is shown as a typical example of full pattern equipment replacing strickles, but surely the economic aspect will depend on the number of castings required, since wood is in short supply and costly. The author discusses semi-permanent patterns, hardwood patterns, hardwood reinforced with metal, filed-up metal patterns, pressure-cast metal patterns, part filed and part machined metal equipment, fully machined metal equipment and the machinery employed, and gives particular attention to plastic patternmaking, which is the latest addition to modern patternshop activities.

Heavy Electrical Castings

The production of heavy castings for electrical generating equipment, described by Mr. N. Charlton before a very large audience, was supplemented by an excellent film which not only showed the preparation of moulds and casting processes, but also the general arrangement of a modern foundry and the facilities provided for dealing with the problem of dust. The foundry and the methods employed, described by the author, deal with developments in the works of C. A. Parsons & Co. Ltd. As the author states, production of castings for turbo-generating equipment is skilled work and presents problems that cannot lightly be set aside. Opinions will differ on the type of mould best suited for these castings. At this foundry, all moulds and cores for large castings are produced by loam moulding methods, the moulding operation being assisted by the use of a Sandslinger to back up with sand the loam facing applied to the pattern. Reference is made to the use of silicon-carbide blocks as chills. Particular attention is directed to the cleaning of castings and to sand handling, and reference is made to the dust-extraction equipment installed.

Other Large Castings

Immediately following Mr. Charlton's paper, another paper was presented dealing with practice in the manufacture of propellers and other castings. It was presented by Mr. C. W. Stewart who reminded members that the work described in his paper is carried out in an old established foundry originally laid out for the production of smaller castings. Modifications have been necessary to deal with castings up to 35 tons and the best had to be made of the limited space available. Moulds for propellers are built in loam, but other moulds for large castings are usually a combination of dry sand and loam. Propellers have been a speciality of the author's firm for many years and are now made from 4 ft. to 19 ft. 3 in. diameter, with three, four or five blades, as required. Two moulders with two labourers make a four-bladed propeller in four days, using loam moulding technique. The production of several types of castings with which the author's firm have had considerable success, notably large gear wheels, gear cases, and castings for reciprocating engines, are also described.

Systematic Study of Casting Defects

Although considerable progress has been made in foundries with the object of improving production methods, careful control of foundry operations will effect a reduction in scrap and defective castings, and Mr. G. W. Nicholls and Mr. D. T. Kershaw discuss this subject in a paper dealing with a system of studying casting defects in a jobbing foundry producing castings weighing from ounces up to 30 tons, and in moulds made by hand ramming, Sandslinger, and machine methods. As a result of a study of the subject, the authors have developed a recording system which is described. As is pointed out, the success of the system is dependent largely on the efficiency of the laboratory as a production unit in controlling the various operations daily performed in the foundry.

Casting Characteristics of Aluminium Alloys

Three papers were concerned with aluminium alloys and the production of castings. The first, by Mr. D. C. G. Lees, deals with casting characteristics of some aluminium alloys ; some sixteen alloys from the British Standard or Ministry of Supply D.T.D. specifications are discussed. The results of an investigation of these alloys have made it possible to outline their casting properties and other factors influencing the ease with which the alloys are handled in the foundry. The main conclusions are summarised under the various properties that make up the casting characteristics, such as : susceptibility to hot tearing ; effect of internal shrinkage porosity on mechanical properties ; pressure tightness when feeding is restricted ; ease of handling alloys in the foundry—difficulties in degassing, treatment of melts, difficulties in obtaining maximum mechanical properties, fluidity attainable.

D.T.D. 424 Alloy

The second paper, by Mr. A. P. Fenn, deals with D.T.D. 424—the versatile light alloy—and is intended to show that this alloy, which has been in use as a general purpose alloy since 1939 for castings that are lightly stressed, is capable of giving much greater service in the engineering field. After a brief survey of the development of this alloy, the author shows that by various heat treatments a considerable range of mechanical properties can be obtained, and points out that it is equally suitable for the three main processes used for the production of light alloy castings, viz., sand casting, gravity die-casting, and pressure die-casting. The methods used to produce a casting in this alloy, having a finished weight of 7,207 lb., are described.

Aluminium Casting Alloys

The third paper of this series is on the production and properties of aluminium casting alloys and is by Mr. F. H. Smith who, after a brief survey over the comparatively short period during which the founding of aluminium alloys has been carried on on a commercial scale, discusses the development of alloys. Although he does not include every type of British alloy, it can be seen that 50 years' expansion has provided a range of

alloys with widely differing compositions, properties and characteristics, which are applied for a wide range of purposes. Aluminium alloy castings are produced at present at the rate of nearly 60,000 tons a year, which is a measure of the casting alloys consumed, and about 87% of the material used for this purpose is secondary metal, produced from various forms of scrap aluminium. It is with the production of secondary aluminium alloy ingots that this paper is primarily concerned. The refining of scrap and subsequent production of ingots to specification are discussed very thoroughly and in an interesting and informative manner.

Dust in Steel Founding

As referred to in the Presidential Address, the problem of dust in foundry operations was considered in two papers. This is a subject to which considerable attention has been directed in recent years, but conditions in foundries are such that the development of means to overcome the problems involved are very complex. In the first paper, which is concerned with the reduction of dust in steel foundry operations, the author, Mr. W. A. Bloor, has recorded the extensive research work in hand by the British Iron and Steel Research Association for improving the dust conditions in steel foundries. Methods have been developed for measuring and continuously recording dust concentrations, and these methods have been used in foundries to explore the source, composition and concentration of dust. As would be expected the dust concentrations have been shown to be very variable from foundry to foundry, and from operation to operation, and the importance of isolating dusty operations and removing the dust at its source have been clearly demonstrated. Some details are also given of more fundamental work, sponsored by B.I.S.R.A., and conducted in university departments, into the specific effect of foundry dust upon animal systems.

Observation and Control of Dust in Dressing

The second paper was divided into two parts, one by Mr. R. F. Ottignon dealing with control of dust and the other by Mr. W. B. Lawrie on its observation, and both are concerned with dressing operations in the foundry. New methods are described which have been developed to observe and control the dust cloud generated during certain fettling operations, because it was considered that the existing methods of applying local exhaust ventilation were not completely effective, and that it was desirable to have some method of observing the path of moving dust clouds. The work described deals with the application of local exhaust ventilation to the dressing of small and medium size castings for which two dressing benches were constructed. One of these benches was fitted with local exhaust ventilation only, whilst the other, more successful bench, was provided with local exhaust ventilation, assisted by an air-jet which imparted to the dust a movement in the required direction. Existing methods of dust estimation indicate the amount of dust present at a particular time and a specified point in space, but it was considered that valuable information would be obtained if the actual movement of the dust could be seen or recorded. This was done by a macroscopic observation of the dust cloud under conditions which are similar to those used in the application of the Tyndall phenomenon to the ultra microscope. Cinematograph film staken to show the clouds observed at different processes, both with and without local exhaust ventilation, were shown on the screen. The results of the work described indicate that increased efficiency in the application of local exhaust ventilation may well be attained by using an air jet to control the direction in which a dust cloud flows ; it also appears that further aerodynamic studies are essential to effective local exhaust ventilation.

Mechanical Charging of Cupolas

Mr. W. J. Driscoll, in a paper on mechanical charging of cupolas, surveys the methods in use and the principles involved. For this purpose a mechanical cupola charging installation is considered as one where each metal charge for the cupola is made up and weighed at about ground level, and where each charge is subsequently hoisted, moved to the cupola if necessary, and discharged into the furnace without further manual handling of the materials of the charge, or of the skip or bucket in which they are contained. The main characteristics of chargers of this type are described, but no attempt is made to cover detailed points of design which may have been introduced by particular equipment manufacturers.

The author compares hand and mechanical charging and directs attention to the advantages of the latter method. He then discusses cupola design as affected by mechanical charging and the factors that determine the choice of mechanical charging system. Various types of charging skips and buckets are described and their relative merits discussed. Types of hoists and chargers are described and the weighing of metal charges and their movement to the charging system are discussed. The importance of maintaining control of the coke and limestone charged is emphasised, and attention directed to storage hoppers and the arrangement of the stock yard. The labour involved in operating cupolas is also discussed.

Steelfounding Radiography

Present-day steelfoundry radiographic practice is reviewed in a paper by Mr. G. M. Michie, sponsored by the Research and Development Division of the British Steel Founders' Association, in which, after briefly tracing the history of industrial radiography, he refers to some of the radiation sources now available to the industrial user. Attention is particularly directed towards the availability of artificially-prepared radioactive isotopes, which materials, together with X-rays, radium and radon, are now in general use in many steel foundries. Consideration is given to the physical characteristics of each type of radiation source and to their respective merits in relation to radiographic practice. Emphasis is placed upon the importance of fully recognising the care with which safety precautions must be observed in practice, reference being made to such considerations as protective enclosures, gamma-ray source containers, the tolerance dose, blood counts and other means of checking and preventing excessive radiation dosage. Safe working distances from various gamma-ray sources are diagrammatically indicated. The field of application of radiography in the steel foundry is then reviewed, reference being made to such problems as the interpretation of radiographs and the use of acceptance standards. The author expresses the view that the more general application of radiographic methods, now made possible through the availability of cheap radio active isotopes, constitutes a major step

towards the extended application of steel castings in many fields of engineering practice.

Reports of Sub-Committees of the Technical Council

The activities of the Technical Council, through its various Sub-Committees, is indicated by the fact that three reports and recommendations were presented for discussion at this Conference.

Synthetic Resin Binders

The first of these to be submitted was from Sub-Committee T.S.30 which was appointed early in 1949 to investigate the use and development of synthetic resins for corebinders, moulding sand binders, and other foundry applications. The Sub-Committee's report is based on a combination of replies to a questionnaire circulated to foundries believed to have knowledge of the subject, and it is confined to the use of synthetic resins as corebinders. Several foundries can show that the advantages of synthetic resins for this purpose are real; others, on the other hand, have rejected them on the score of odour and/or production difficulties. It is emphasised that accepted methods for oil-sand must not necessarily be carried on with a changeover to resin sand, and the new binder must be treated with respect and methods adapted to suit its characteristics. The Sub-Committee endorses the recommendations of the British Plastics Federation that foundries make use of the technical services of the resin suppliers to obtain the best results from any particular type of resin. Neither urea-formaldehyde resins nor phenol-formaldehyde resins evolve the irritant fumes associated with oil-bonded sand cores, but the fumes from the former are disagreeable. Synthetic resins are home produced and in ample supply; the cost of mixed sand is generally about the same as that of comparable oil-bonded sand, but savings accrue due to reduction in baking costs and, in some cases, fettling costs may be reduced.

Evaluation of Soundness in Cast Iron

A report was submitted by Sub-Committee T.S. 20 on the evaluation of soundness in cast iron. The object of the work involved was not concerned with the causes of unsoundness in castings, but with means of locating or detecting the unsoundness and determining its nature and extent. While no limit was placed on the methods examined, in the preliminary discussions of the Sub-Committee the following conclusions were recorded: (*a*) Unsoundness is to be interpreted as including all forms of internal porosity, inclusions and gas holes; (*b*) the use of different testing methods for assessing different forms of unsoundness in various shapes and sizes of casting may be advisable.

Various destructive tests to assess the soundness and strength of castings are well known and in common use. The results of such tests can be either qualitative or have quantitative values, which by comparison with the maximum value for a sound specimen of similar material, may be taken as a measure of the degree of unsoundness of the castings. These tests often reveal only the weakest spot in the casting or specimen, rather than the total unsoundness, and may be quite unsuitable as a means of measuring the influence of mould materials. Successful non-destructive methods have obvious advantages in production, and the Sub-Committee focused its attention primarily on such methods of examination, in particular to radiographic and ultrasonic methods.

After a detailed investigation of various non-destructive methods the conclusions of the Sub-Committee are summarised as follows:—

1. For the precise location and delineation of any form of unsoundness which produces a local variation in opacity to γ or X-rays, radiography can be recommended. Limitations are imposed by (*a*) section thickness much in excess of 6 in. to 8 in., and (*b*) the failure of radiography to identify evenly distributed porosity of small size in grey cast iron. This may effect its usefulness in work on the influence of moulding materials.
2. Quantitative evaluation of unsoundness by radiography can only be achieved by comparison with carefully prepared comparator charts.
3. The principal advantage of ultrasonic methods lies in their application to thick sections beyond the range of X-rays. Major defects, discontinuities and areas of unsoundness can be located, and an experienced operator can obtain a quantitative measure of the unsoundness, preferably by using the relative absorption factor method which is described in the report. Limitations on sensitivity are imposed in examining grey cast iron by the presence of free graphite and, as with radiography, uniformly dispersed fine porosity is not detected.
4. The electrical and magnetic methods examined proved of very limited value, except to distinguish between sound and unsound test pieces of simple geometrical form.
5. The determination of relative density is of limited value, since the effect of variations in coarseness of structure and graphitic carbon content severely limits the usefulness of this comparatively simple test. Under suitably controlled test conditions, density is found to be directly related to soundness, although neither the type nor the distribution of the unsoundness can be defined.

Other methods, such as indentation hardness, pressure tests, and vitreous enamelling were examined, but these proved unsuitable for general use.

Heat Treatment of Grey Cast Iron

The third report, that on the heat treatment of grey cast iron submitted by Sub-Committee T.S.31, covers work, of a broad general nature, on the application of heat treatment to grey irons, including those accidentally chilled. The Sub-Committee has been chiefly concerned to pick out matters on which there seems to be a real lack of knowledge, or where the industrial practice varies so widely as to suggest that the heat treatment operations could be more effectively or more economically carried out with a better understanding and application of the principles involved. There are three points on which the Sub-Committee feel that further investigations would be useful: (1) Although there is a large volume of information on the question of pearlite breakdown in normal irons, there is little available information on the response of unusual compositions and, especially, modern alloyed irons containing nickel, chromium, copper and molybdenum, either singly or in combination. The effect of graphite size and distribution as cast, and of section thickness, could also be usefully studied. (2) The removal of massive free carbides in iron accidentally chilled, where the composition is unusual by reason of very low or very high silicon, unbalanced sulphur, or the presence of nickel, chromium, copper and molybdenum, either singly or in combination. (3) The influence of the rate of cooling through the critical point on the residual combined carbon of irons heat treated at temperatures

above the critical is not at all clear, and could usefully be investigated in relation to the chemical composition.

Works Visits

As with previous Conferences organised by this Institute, considerable attention was given to the works visits and the types of works included in the programme covered a wide range, enabling members to make a choice in keeping with their individual wishes. These visits were well attended and as in every case work was proceeding on a normal basis, members had opportunities of discussing methods of production with those actually engaged on the work, in the light of prevailing conditions, with mutual benefits.

Creep and Fatigue Properties of Non-Ferrous Metals at Elevated Temperatures

Recommended Scope of Research Programmes

SHORTLY after the conclusion of the war, the Light Alloys Sub-Committee of the Ministry of Aircraft Production Metallurgical Research Committee reviewed the position in the above field. Under the chairmanship of Professor L. Aitchison a policy was framed for the guidance of workers employed on investigations for the Government Services on the subject of creep. A memorandum incorporating the Sub-Committee's recommendations on this subject was drafted in 1947. At the same time thought was given to corresponding investigations on fatigue.

When, in 1948, the Ministry's Research Committee was superseded by the Inter-Service Metallurgical Research Council, consideration of this subject was continued by the Non-Ferrous Metals Committee of that Council under the chairmanship of Mr. (now Professor) A. J. Murphy. In due course a further memorandum was produced incorporating that Committee's recommendations on the subject of research on fatigue of metals at elevated temperatures.

These memoranda were primarily intended to help in the formulation of government research policy. No extensive series of researches was directly initiated to implement these various recommendations, which were regarded as providing a co-ordinating policy within which investigations in this field could, by paying attention to the broad aspects suggested in the memoranda, be directed towards the provision of information of the greatest general benefit. Research into the mechanism of creep and fatigue was not regarded as coming within the scope of these recommendations.

Within the somewhat limited range of laboratories concerned this policy has met with success. Investigators studying some particular application of metals or alloys at high temperatures have been pleased to broaden their work to bring it within the scope of the general recommendations made. For this reason the Non-Ferrous Metals Committee of the Inter-Service Metallurgical Research Council has recommended the issue of a general statement summarising the views expressed and recommendations made in the earlier memoranda, with the object of giving an opportunity to all investigators working in this field who may wish to do so to modify and direct their researches in such a way as to contribute the maximum amount of useful information on the behaviour of metals and alloys when subject to creep and fatigue conditions at high temperatures.

The approach to this matter by the Committees concerned has been a desire for the greatest amount of fundamental information on the behaviour of metals under these conditions. It is inevitable that many laboratories are primarily concerned with providing data on the creep and fatigue resistance of specific alloys. The values thus obtained are available to engineers and may contribute in some measure to the general understanding of the phenomenon concerned. It may happen, however, that those investigators who have made tests with a view to providing data are not in a position to extend them sufficiently to provide information of fundamental scientific value. There are, within the Committee's knowledge, certain researches in this field which could be so extended with little additional time and effort and whose value, therefore, in their contribution to our general knowledge, could be greatly enhanced.

This note is not published with the intention of attracting a number of new workers into this field. Admittedly, an enormous amount of further knowledge on these subjects is needed, but, in view of the heavy demands for research workers on other aspects of metallurgy, an intensive attack on creep and fatigue might absorb an effort that would be out of proportion to the probable immediate benefits. Publication, however, will have served its purpose, if it encourages those who of necessity or by desire are working in this field to try to fit their investigations into the framework which is here described.

Factors Recommended for Consideration

It is suggested that the most important general approach in this matter should be an orderly investigation of the influence of variables in metallographic structure and in composition on creep and fatigue resistance at elevated temperatures. The following factors are considered to be important :—

A. Factors relating to the matrix

- (i) Grain size
- (ii) Orientation
- (iii) The effect of prior mechanical strain and of the manner in which this is effected
- (iv) Effect of solute metals present in allowing proportions in solid solution
- (v) Effect of small amounts of dissolved impurity
- (vi) Crystal structure of the matrix crystals (i.e. face-centred or body-centred cubic, hexagonal, etc.)

B. Factors relating to the second, " dispersed " phase

- (i) Distribution of particles (e.g. grain boundary distribution or uniform distribution)
- (ii) Particle size
- (iii) Amount of second phase present
- (iv) Nature of second phase present (whether " intermetallic compound " or " electron compound "

etc.—influence of crystal structure and other properties of second phase)

C. *Temperature dependent factors*

Relaxation towards equilibrium of non-equilibrium structures at the elevated service temperatures, recrystallisation, grain growth, absorption or globularisation of precipitates, etc. and the influence of stress on such structural changes.

Materials Recommended for Study

As will be obvious from the fact that this approach to the subject was suggested by the Light Alloys Sub-Committee, aluminium alloys were primarily in mind at the outset. It was, however, felt throughout all these discussions that the work should not be confined to aluminium alloys, but that a number of different solute and solvent metals must be considered if information of general application is to result. The Committee has accordingly made the following more specific recommendations.

Bearing in mind the large number of variables referred to above, it is clearly necessary to choose for examination systems in which there is a reasonable prospect of studying these factors separately and in which, therefore, such factors as alloy constitution are already well known. It is furthermore considered that the work should be carried out using pure materials so that the effects of impurities may later be investigated separately, and that in the initial stages of the work the materials should be in structural equilibrium at the temperature of the test, prior to the start of the test. The information resulting as to the behaviour of the material under such controlled conditions will provide a background against which subsequent work on the behaviour of non-equilibrium structures is less difficult to interpret. The importance of a full and detailed description of the specimens tested and of their method of manufacture, including surface finish, cannot be overemphasised. In some investigations already in progress or contemplated, it may only be possible to make a specific and accurate measurement of grain size, composition, and any tendencies to preferred orientation in the specimens used and to record all available details of their history. The provision of such information gives a greatly enhanced value to the results of what might otherwise be an *ad-hoc* creep or fatigue test on an ill-defined specimen.

(*a*) *Factors Relating to the Matrix*

For studies of the effect of factors associated with the matrix, the alloys chosen must remain reasonably homogeneous over a range of compositions and temperatures. In this section of the work investigations on pure metals and on single crystals had rather less encouragement than the investigation on alloy systems, except insofar as the study of the pure metal is necessary to compare its behaviour with that of a solid solution based thereon. While, in Section A, Item (iv) is perhaps receiving the greatest emphasis in work now in progress, the other items should clearly receive simultaneous consideration since the behaviour of a poly-crystalline aggregate will be profoundly affected by grain size, orientation and other such matters.

Alloy systems particularly mentioned as worthy of consideration in this part of the work are the aluminium-zinc, aluminium-magnesium alloys, and copper-base alloys in which the valency of the solute can readily be varied (the lattice distortions produced by a large number of elements in copper are accurately known and can therefore be directly compared with mechanical properties). Magnesium alloys such as those with cadmium or aluminium provide materials based on a hexagonal metal, and iron which can exist in face-centred cubic and body-centred cubic forms provides an opportunity of correlating properties with changes in crystal structure.

(*b*) *Factors Relating to the Second Phase*

Systems in which the second phase is completely insoluble in the solid state are difficult to find, but some work is in progress in co-operating laboratories on aluminium-iron and lead-copper systems where this condition is approached.

The effects of the mode of occurrence, distribution, and particle size of a dispersed phase could be studied in the system aluminium-copper about the precipitation processes in which much is already known. In this case a definite intermetallic compound of limited homogeneity range is formed. Research should preferably be planned to include the effects of different types of dispersed phase. Many systems of the "aluminium plus intermetallic compound" type are available, while in the system aluminium-magnesium there is an intermediate phase of relatively wide homogeneity range. It may be necessary at some stage of the work to extend investigations to the effect of second phases of the "electron compound" type, in order to complete the picture.

(*c*) *Temperature Dependent Factors*

The effect of these variables could be examined using the aluminium-copper system or perhaps, better, in some system such as aluminium-magnesium where the variation of solubility with temperature is more pronounced.

General Observations

It is not intended in this note to do more than indicate an approach to the problem and a general line of thought. Metallurgists will no doubt think of alloy systems other than those mentioned above, a study of which could profitably form a part of the general investigation here outlined. It is only desired to emphasise that a programme of this general type might be expected to give information with regard to the effects of several factors treated, as far as possible, separately. The success or otherwise of the correlation would tend to reveal whether factors other than those enumerated should be considered. More complex alloys, more normally related to alloys at present in service, could then be examined and developed in the light of the knowledge gained.

It cannot be too strongly emphasised that there is no desire or intention in the minds of the Committee to direct researches on creep and fatigue of metals into any unduly narrow channel. The Committee's object is only to call the attention of all interested parties to the desirability of carrying out work in this field on such materials and in such a way, wherever possible, as to make the most effective contribution to our structure of knowledge on the subjects.

The Non-Ferrous Metals Committee would welcome information as to the particular researches of investigators working in this field. Those interested should communicate with the Secretary, Non-Ferrous Metals Committee, Inter-Service Metallurgical Research Council, Metallurgy Department, Royal Aircraft Establishment, Farnborough, Hants.

New Simon Research and Development Building

General view of the Research and Development buildings. On the left is the main Simon-Carves' laboratory block, behind which are the development building and further laboratories. The tower on the right houses the Henry Simon experimental flour Mill.

THE Simon Engineering Group's new research and development buildings were formally opened on July 3rd by Sir Henry Tizard, G.C.B., A.F.C., F.R.S., Chairman of the Advisory Council on Scientific Policy, at a luncheon to over 300 guests representing the senior levels of the industrial and scientific world, and of various Government departments.

In the course of his speech proposing the toast of "The Guests," Lord Simon of Wythenshawe said that one of the main considerations leading to the spending of a quarter of a million pounds on the new buildings and their equipment had been the realisation that research and development had to be tackled on a new scale if they were to compete successfully in the world's markets and so increase exports. In the last five or six years they had achieved some £25 million of exports to some 40 countries, including the U.S.A. and Canada,e and an important item in the present order book concerned a large coke oven battery for America. At the same time there was a heavy programme at home in building power stations, coal preparation plants, coke ovens for new or enlarged steelworks such as Margam and Shotton, and a number of sulphuric acid plants, including the United Sulphuric Acid Corporation's £3½ million project for plant at Widnes to produce sulphuric acid from anhydrite, and the I.C.I's £1½ million anhydrite scheme at Billingham, for both of which Simon-Carves had been appointed main contractors.

Lord Simon emphasized the interdependence of home and export markets. Neither, alone, could support the organisation at the size it had now achieved, a size which was essential if they were to undertake research and development on the scale necessary to compete in world markets. The export efforts called for first-rate technical know-how; that in turn demanded not only the enlarged scientific staff and resources with which they had equipped themselves, but also a good home market, in which they could build plants which were immediately accessible for operational study.

The New Laboratories

The new buildings have enabled many separate laboratories and experimental plants, formerly scattered over some 80 acres, to be centralised in a single block of modern buildings, with expanded and improved resources, and with accommodation for an enlarged and strengthened scientific staff.

The Research Department is a central organisation serving all the Simon-Carves contracting departments, and its work covers mechanical and chemical testing, research, and information: the organisation of the last two on a central basis is a recent development.

No less than nine laboratories are devoted to the preparation of coal samples, "washability tests, and examination of the coking qualities of coals for carbonisation, and of the calorific value, ash fusion and grindability of coals for boiler firing." Extensive facilities are also provided for testing refractories, and for the metallurgical examination and mechanical testing of materials used in plant construction. For general chemical analysis, there is a large analytical laboratory.

There is not likely to be any dearth of subjects for research. One field of common interest to several departments is the behaviour of small particles, with special reference to sedimentation, the collection, extraction and disposal of industrial mists and dusts, pulverisation of coal, combustion of pulverised fuel and sulphur bearing ores, and magnetic properties. A major problem at present is the supply of sulphur for sulphuric acid production, and among sources under consideration are recovery from waste gas and flue gases, removal as hydrogen sulphide from town's gas, and the flash roasting of iron pyrites. Other problems offering ample scope for work are those of effluents from gasworks and coke oven plants, and the corrosion of metals used in plant construction. There are too, a number of long-term fundamental investigations.

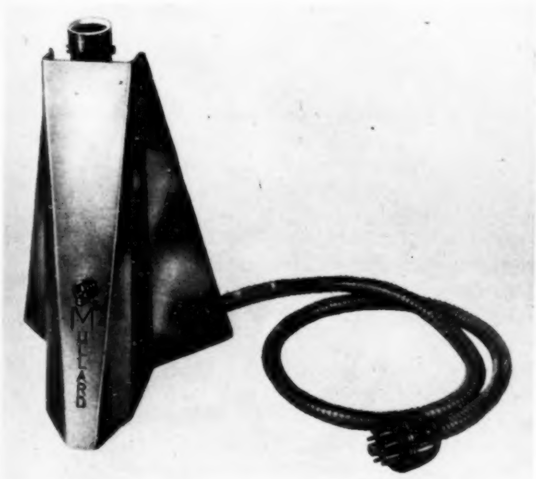
Development work, which is dealt with departmentally rather than centrally, falls into two categories. In the first, new principles are involved and pilot plant work is called for, whilst the second class necessitates the study of the operating characteristics of existing full-scale plants. The erection of pilot plants is provided for by the Development Building, whilst site investigations are facilitated by a mobile laboratory. A number of pilot plants, at various stages of development, are housed in the Development Building. They include a coal washing plant, a coke oven, and a distillation plant. It is also intended to instal in this building a combustion pot to determine the behaviour of solid fuels on travelling grate stokers and spreader stockers, and a new type of pulverisor. Another test rig is planned for experimental work on joints for high pressures.

RECENT DEVELOPMENTS

MATERIALS : PROCESSES : EQUIPMENT

An Ultrasonic Soldering Bath

THE rapid tinning of small aluminium and aluminium alloy articles is made possible by an Ultrasonic Soldering Bath recently introduced by the Equipment Division of Mullard, Ltd. This unit has been specifically developed for the soldering of small and complex shaped parts which cannot easily be handled by the well-known Mullard Ultrasonic Soldering Iron. Included in this category of work are such items as foils, wire and tubes. The Mullard Soldering Bath should also find extensive use in the making of connections for condenser foils, in the tinning of aluminium galvanometer suspensions, and in the soldering of small tubes and sections to anchorings or mountings.



The new soldering bath has been designed to operate from the same power supply unit normally supplied for use in conjunction with the Mullard Ultrasonic Soldering Iron. It consists of a small soldering bath $\frac{7}{8}$ in. diameter and $\frac{3}{8}$ in. deep. This is heated by means of a conventional resistance winding, and the molten solder in the bath is agitated ultrasonically by means of a magnetostriction transducer composed of a stack of iron alloy laminations. A control switch on the front of the unit enables the ultrasonic energy to be applied at will.

In the new soldering unit the rapid vibration of the bath, resulting from the magnetostriction effect produced in the transducer, is used to break up the highly refractory oxide films which normally form very easily on such metals as aluminium. In the past, one of the few effective ways of removing these films has been through the use of fluxes which, on the application of heat or special liquids, release a nascent element that stimulates a violent reaction with the oxide. This is a most unsatisfactory method as the reaction is only of short duration and the oxide film re-forms immediately the reaction ceases. This difficulty is overcome with the Ultrasonic Soldering Iron and Bath, and positive and uniform joints can be easily obtained.

The soldering procedure is quite simple. The bath is allowed to heat to its usual operating temperature. The transducer is then energised by closing the switch on the front of the unit. After this, articles can be tinned simply by immersing them into the molten solder contained in the bath. An important advantage of this method is that no flux is required. Moreover, soft solders may be employed. To avoid electrolytic action when soldering aluminium and its alloys there may, however, be advantages in using a tin-zinc instead of the usual solder with a tin-lead base.

The ultrasonic power necessary to drive the transducer is supplied by an electronic amplifier comprising the power supply unit. This unit is housed in a metal case with handles and may easily be carried around the factory. It is suitable for operation from 100–250 volt, 40–60 cycle mains supplies and has a total power consumption of about 200 watts. Connection with the soldering bath is by a simple multicore cable, which supplies both the heating winding and the transducer excitation and pick-up coils. The only control on the supply unit is the amplifier switch.

The dimensions and weights of the units comprising the equipment are as follows : soldering bath—$6 \times 6 \times 9\frac{1}{2}$ in., 4 lb. ; supply unit—$9 \times 10 \times 12$ in., 40 lb.

The use of high impedance coils eliminates the necessity of using transformers for coupling. This simplifies the amplifier circuit and reduces weight.

Soldering baths employing larger transducers and operating from higher powered ultrasonic generators can be supplied.

Mullard, Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

Casting Reclamation Process

A NEW development in the repair of defective castings, the Dot-Weld process, is now made available for use in this country. Suitable for filling in surface blemishes and shrinkage areas, blow holes, pinholes and sand holes revealed in machining, and building up worn core boxes and faulty patterns, several advantages are claimed for the process. The Mogul Quench Arc Weld machine—a high-amperage, low-voltage unit operating on alternating current, is connected to the electrode holder—the Dot-Weld Pistol—which has a specially designed air pressure unit which directs a constant stream of cold air down and around the electrode and on to the job. The electrode is automatically fed to the work by means of a finger-trigger friction drive residing in the pistol handle. Incorporated in the pistol is an air cylinder which vibrates the electrode, thus making and breaking the arc, and resulting in the rapid application to the work of a large number of small dots of fused metal. This patented feature obviates the danger of high temperatures being developed in the base metal, thereby eliminating heat stresses, distortion and hard spots. This is shown by the fact that the operator can touch the weld immediately the pistol is taken away from the job without feeling more than a slight warmth.

Dot-Weld can be applied to castings of aluminium (sand and die castings), bronze, steel, malleable iron and cast iron. The unit does not require a skilled operator, is extremely mobile, and maintenance costs are negligible. An important advantage is the ability to carry out repairs without removing the casting from the machine.

Other uses to which the process has been applied with success include: the application of metal to mis-machined surfaces; repair of cracked motor blocks, heads, etc.; building up of both external and internal diameters for press misfits; and preparation of hardened surfaces as a bond for sprayed metal.

British Ronceray, Ltd., Electrical Dept., Benefit Buildings, Moorhead, Sheffield, 1.

CURRENT LITERATURE

Book Review

BASIC REFRACTORIES—THEIR CHEMISTRY AND THEIR PERFORMANCE

By J. R. Rait, 410 pp., 109 illustrations, 112 tables. Published December, 1950, for "Iron and Steel," by Iliffe & Sons, Ltd., London. 60s. net. By post, 60s. 9d.

THIS new book must be considered by any standards to be a very important contribution to the literature on refractories technology, which contains very few textbooks of this quality. The book deals mainly with the compositions and constitutions of typical bulk-produced basic refractory materials. It is a notable fact that, with the exception of magnesite produced by the sea-water process, all basic refractories are made, without any purification process, from selected naturally occurring ores, often extremely complex, or mixtures of ores. It is equally obvious from the text that most of the research work described has been concentrated on the constitution of the ores available under present conditions, and of the multi-component oxide systems which cover the fired products. That is to say, the work has been concentrated on elucidation rather than development.

The major part of the book, therefore, consists of providing from published work, augmented where necessary by the author, thermal equilibrium data on the $CaO - MgO - SiO_2 - Al_2O_3 - Fe_2O_3$ system. From this study the chief objects are:

(*a*) To predict the mineralogical constitution of dolomites and magnesites from various sources from their chemical composition. This was checked quite well by X-ray and petrological estimates of the phases in the refractories.

(*b*) To predict the temperature of first liquid formation and the amounts of liquid formed at given higher temperatures. It is pointed out that these liquid contents are more important in basic than in siliceous refractories due to the high fluidity of the liquids in the former. The proportion of liquid present appears to correlate quite well with the refractoriness-under-load test results.

The fact that the application of thermal equilibrium data to these basic refractories is in good agreement with the constitution and behaviour of the refractories disposes of the view that such refractories are not equilibrium products and justifies the approach used here.

The presentation of data on complex systems such as this is a difficult problem to which an ideal solution has not yet been found, and the method employed by Dr. Rait certainly does not result in conciseness. The section on performance is not as general as one would expect in a textbook and consists largely of detailed examination of bricks before and after service, in a few steelmaking furnace campaigns. The weak point, and a very common one in this field, is the lack of any satisfactory correlation between the serviceability of the refractory and its properties. In spite of these defects and a few obvious errata the work forms a valuable reference book.

W. A. ARCHIBALD.

Books Received

"CRYSTAL GROWTH," by H. E. Buckley, D.Sc., 571 pp. inc. appendix, 169 line drawings and 88 plates. John Wiley & Sons, Inc., New York, and Chapman & Hall, Ltd., London, 1951. 72s. net.

"Standard Methods of Analysis of Iron, Steel and Ferro-Alloys" 4th edition, 169 pp. The United Steel Companies, Limited, Sheffield, 1951. 17s. 6d. (in Great Britain).

"A.S.T.M. Methods for Chemical Analysis of Metals—1950 Book" 476 pp. inc. index. Copyright 1950 by The American Society for Testing Materials. Cloth bound $6.50, interleaved $9.00.

"International Conference on Hot Dip Galvanizing held at Copenhagen, July 17th 21st, 1950," 160 pp., with tables and illustrations. Hot Dip Galvanizers Association (affiliated member of the Zinc Development Association, Oxford, 1951. 30s. net (cloth bound).

"Industrial Polishing of Metals," by Gerald F. Weill, 202 pp., with 97 illustrations. Published for "Metal Industry" by Iliffe & Sons, Ltd., March, 1951. 21s. net (postage 8d.).

"Symposium on Ultrasonic Testing." Special Technical Publication No. 101, 140 pp. with illustrations. Copyright 1951 by the American Society for Testing Materials.

"Symposium on Rapid Methods for the Identification of Metals." Special Technical Publication No. 98, 84 pp. with illustrations. Copyright 1950 by the American Society for Testing Materials, $1.75.

Tool Steel Catalogue

A new and up-to-date edition of the E.S.C. "Tool Steel" Catalogue is now available from English Steel Corporation, Ltd., Sheffield. This publication, which is excellently produced, contains in easily accessible form, much valuable information on the application, manipulation and heat-treatment of E.S.C.'s high-grade tool steels. Following a brief general discussion of forging and heat-treatment, each steel in the range is dealt with in detail, the information given including characteristics, typical uses, approximate analysis, condition as supplied, heat-treatment, and any special information.

METALLURGICAL DIGEST

Pearlitic Malleable Irons can be Successfully Surface Hardened

By S. H. Bush, F. B. Rote and W. P. Wood

WHEN a hard, wear - resistant surface, produced by flame or induction hardening, is added to the other desirable properties of pearlitic malleable castings, the number of possible applications is greatly increased. Typical examples of applications (existing and potential) in the motor-car and other industries are: engine valve rocker arms, rocker arm shafts, transmission shifter forks, fuel pump liners, cam shafts, engine cylinder liners, wheel hubs, external and internal gears, cams, sprockets, refrigerator crank shafts, rifle receivers, rolls, pneumatic tool cylinders, forming dies, lathe beds, armour plate, clamps, micrometer frames, etc.

Proper methods and control of variables produce cases averaging 60 to 62 Rockwell C on the surface and depths of case capable of variations from as low as 0·05 in. to any desired depth, with no loss in uniformity of hardening. Proper control also eliminates dangers of spalling, decarburisation, sweating, or excessive porosity due to loss of temper carbon.

Results of a series of experiments on nine commercial pearlitic malleable irons conducted at the University of Michigan verified the fact that the most important variable is the matrix microstructure of the iron. It was found that chemical composition and graphite size, shape and distribution were secondary factors. The most satisfactory microstructure proved to be one made up of finely spheroidised cementite. The least satisfactory consisted of a structure of coarsely spheroidised cementite.

Some components, due to their size or shape, can be more satisfactorily treated by flame hardening; others can best be hardened in an induction unit. The size and shape of the casting, area to be hardened, depth of case desired, and method of quenching control, to a great extent, determine the hardening technique.

When heating with an oxyacetylene flame, adequate control of surface temperature and length of heating cycle is essential. Too high a surface temperature causes severe sweating, resulting in a non-uniform layer of white iron on the surface. Too low a temperature gives a non-uniform case of pearlite and martensite with inadequate resistance to wear. Tests made to determine the optimum indicated surface temperature and quenching medium for obtaining a case with a hardness of Rockwell 50C at a minimum depth of 0·06 in. showed that a temperature of 820° C. and an agitated water quench yielded best results.

The curves shown in Fig. 1 indicate the hardness and depth of case of some typical commercial pearlitic malleable irons which have been flame hardened at 820° C. and water quenched. The curve Y represents an iron having a matrix of finely spheroidised cementite.

By proper selection of power input and heating time, as well as proper coil design, it is possible to surface harden satisfactorily most pearlitic malleable irons by induction heating. Experiments conducted with nine commercial irons indicated that all could be induction hardened, but that some were much more responsive than others. Frequencies ranging from 3,000 to 350,000 have proved to be satisfactory. In general, case depth is much greater at the lower frequencies, with non-uniformity in hardness and microstructure. At higher frequencies, due to the skin effect, this difficulty is eliminated. For general use where a uniform case of average depth is desired, a 9,600 cycle unit capable of delivering 75 to 100 kw. is best. The curves shown in Fig. 2, representing several typical commercial pearlitic malleable irons, show hardness and depth of case by induction hardening at 9,600 cycles for 2 sec. Curve Y represents the iron having the most responsive microstructure, consisting of a matrix of finely spheroidised cementite.

With an increased knowledge of the effect of such variables as power input, heating time, type of quench, chemical composition and microstructure, it will be possible to predict, with a greater degree of assurance, the results which can be obtained with pearlitic malleable irons. The results of these experiments

COMPARATIVE PROPERTIES OF
SURFACE HARDENED PEARLITIC MALLEABLE IRON AND SURFACE HARDENED STEEL

Part	Material	Heat-treatment	Depth of Case, in.	Surface Rc before draw
Motor-car camshaft	Steel, carburised case	Carburised, water-quench, draw	>0·060	58–62
Motor-car camshaft	Pearlitic malleable iron	Induction harden	>0·060	58–62
Gear	Alloy steel	Flame harden	0·040–0·060	53–58*
Gear	Pearlitic malleable iron	Flame harden	0·040–0·060	58–62

* Hardness may be greater than 60 Rc according to alloy steel used.

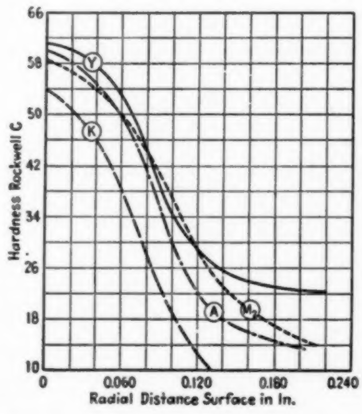


Fig. 1.—Hardness versus depth of case of some commercial flame hardened pearlitic malleable irons.

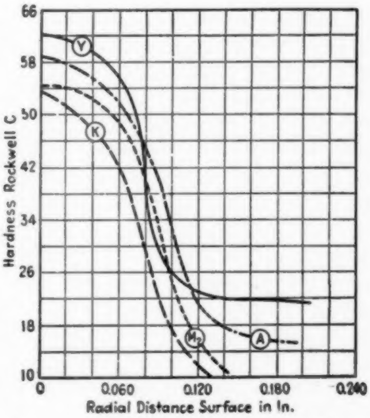


Fig. 2.—Hardness versus depth of case of some commercial induction hardened pearlitic malleable irons.

From *Materials and Methods*, 1951, 33, 70-72.

show that these irons are applicable where a tough core with a fair degree of ductility and shock resistance is desired, in conjunction with a hard wear-resisting case. Comparative properties of surface hardened pearlitic malleable iron and surface hardened steel are shown in the accompanying table.

The Industrial Status of Ductile Iron

By A. P. Gagnebin

DUCTILE iron is now a fully-fledged engineering material manufactured and purchased on the basis of specifications. Although current production is by no means comparable to that of other engineering materials, its present state can be defined as one of healthy infancy. This relatively new cast iron is not a single material but is rather a family of materials. As with steel, the matrix structure may be modified by alloys or heat-treatment to produce austenitic, acicular, martensitic, pearlitic or ferritic structures. Most of the industrial interest so far has been focused on the pearlitic and ferritic grades and it is these grades with which the article is concerned.

Four principal types of ductile iron are being produced at the present time. The first, which has a pearlitic structure, develops about 45 tons/sq.in. tensile strength with 2–5% elongation in the as-cast condition and provides good mechanical wear resistance. The second which has a pearlitic-ferritic structure, has a tensile strength of about 40 tons/sq.in. with 5–10% elongation. It is used to obtain a combination of strength and toughness. The third grade has a full ferritic structure obtained by a short anneal of either of the first two. This has a tensile strength of about 32 tons/sq.in. with 20% elongation and provides optimum machinability and maximum toughness. The fourth contains higher manganese and, more particularly, a higher level of phosphorus than the preceding grades. It is used in applications requiring high strength and stiffness but involving moderate shock.

In the as-cast condition, ductile iron develops a relationship between tensile strength, elongation, and hardness which is shown in Fig. 1. This is an important attribute of the material since hardness provides an index of the other mechanical properties. A number of castings which have been sectioned and subsequently machined into tensile test bars, developed the same relation between tensile strength, elongation, and hardness as that developed in standard test bars, cast with the same metal. Consequently in a properly fed ductile iron casting of known composition, a hardness measurement will indicate the strength and ductility of the casting itself. It should be noted that the relation shown in Fig. 1 applies to irons containing no more than 0·1% phosphorus.

In addition to alloying elements, which influence the proportion of the pearlite and ferrite formed, the cooling rate of the castings in the mould has an important effect on the microstructure. Castings which cool rapidly tend to be pearlitic while those which cool slowly tend to develop ferrite. Consequently, a light section casting cooling rapidly will develop higher hardness, higher strength, and less ductility than a heavy section casting which cools more slowly. The composition of ductile iron should be harmonised with the cooling rate of the casting in order to produce a hardness level corresponding to the properties desired.

Compositions Used and Effect of Alloying Elements

The magnesium process*, on which the production of this ductile iron is based, is applicable to a wide range of base irons, and a number of compositions are used depending on the properties required and the service for which the castings are intended. The broad composition range along with a few specific compositions being used commercially are given in Table I.

The carbon and silicon contents are higher than those normally encountered in engineering grey iron; the carbon plus one-third silicon generally ranges from 4·3 to 4·6%. Broadly speaking, magnesium controls the graphite form but has little influence on the type of matrix developed and, consequently, other elements such as manganese and nickel in conjunction with the cooling rate determine the strength and ductility in the as-cast condition.

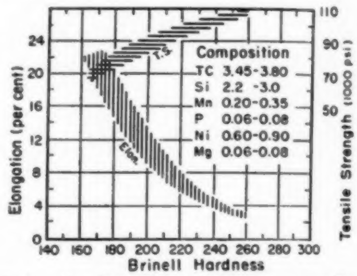


Fig. 1.—Relation between tensile strength, elongation, and hardness of ductile iron in the as-cast condition.

An important and perhaps the outstanding feature of ductile iron is that it combines the fluidity and castability of cast iron with properties resembling those of steel. There have been a number of component parts which could not be manufactured because they were too intricate to be cast in steel and had inadequate properties even when made of the best grades of grey iron.

Ductile iron has been tested successfully, and it is now possible to produce this machinery. This kind of situation exists with respect to rotary compressors. There has been a desire for some time to use more efficient refrigerants which have a wider pressure cycle than those now in use, but this could not be done because the complexity of the castings prevented their being cast in steel and they would have been too heavy and bulky to be practicable in grey iron. The advent of ductile iron has made it possible to produce these complex castings. The combination of castability and high mechanical properties in ductile iron deserves considerable emphasis because it is believed to have an important bearing on its potential use, and it is a feature which will become increasingly evident in new machinery designed to take advantage of the special qualities of ductile iron.

From *Mechanical Engineering*, 1951, 73, 101-108. Based on a lecture given at the Massachusetts Institute of Technology Conference on Nodular Iron, 12th September, 1950.

*The use of magnesium or cerium to produce ductile irons are patented processes.

TABLE I.—COMPOSITION RANGE

	C%	Si%	Mn%	P%	Ni%	Mg%
Broad range	3·2/4·2	1·0/4·0	0·1/0·8	0·10	0/3·5	0·05/0·10
Ferritic high-ductility	3·6/4·2	1·25/2·0	0·35	0·08	0/1·0	0·05/0·08
Ferritic high-strength	3·4/3·8	2·25/3·25	0·35	0·10	0/1·0	0·05/0·08
Pearlitic high-strength ..	3·2/3·8	2·25/2·75	0·6/0·8	0·10	1·5/3·5	0·05/0·08

JULY, 1951 Vol. XLIV, No. 261

Solution Methods of Spectrographic Analysis*

(*Communication from the British Non-Ferrous Metals Research Association*)

An account of the investigations carried out by a Panel, set up by the British Non-Ferrous Metals Research Association, into the applicability of solution methods to spectrographic analysis.

IN recent years the Association's Research Committee dealing with Metallurgical Applications of the Spectrograph has set up a number of Panels to investigate, by co-operative effort, several aspects of spectrographic analysis which were of interest to members. One field in which more information was agreed to be necessary concerned the possibility of using aqueous solutions of metals for analysis instead of solid electrodes. A Panel was therefore set up with the following terms of reference :—

" To devise a simple clean solution or residue method of wide application to the spectrographic analysis of non-ferrous metals."

This paper is an account of the work which the Panel has organised and carried out in its search for a method which meets the requirements.

The members of the Panel were as follows :—

Dr. L. C. BANNISTER† (*Chairman*), British Insulated Callender's Cables, Ltd.

Dr. G. L. J. BAILEY (*Secretary*), British Non-Ferrous Metals Research Association.

Dr. G. BARR, National Physical Laboratory.

Mr. P. T. BEALE, British Non-Ferrous Metals Research Association.

Mr. H. R. CLAYTON, British Aluminium Co. Ltd.

Mr. H. E. R. HARTLEY.

Mr. A. MAYER, Magnesium Elektron, Ltd.

Mr. M. MILBOURN, Imperial Chemical Industries, Ltd., Metals Division.

Mr. C. H. WOOD.

It is well-known that analysis of metals by emission spectrography is most accurate when the samples being analysed match the standards employed for comparison in size, shape and metallographic structure. A laboratory having to deal with samples of assorted shapes and varying metallurgical history would ideally need a very large number of standards, all subjected to careful chemical analysis. In many instances it would not be justified to make up a series of standards to a certain requirement because they might never be needed again. In other cases the matching of a sample would be impracticable, particularly if the previous metallurgical history were unknown.

The effect of size, shape and metallurgical history is, of course, eliminated by taking the metals into solution, and it is evidently practicable to prepare synthetic " standards " of similar composition which need not be analysed chemically.

It is not surprising, therefore, that there exists a widespread need for a spectrographic technique for the comparison of aqueous solutions of metal salts, or of their residues after evaporation. Many such methods have been published but most of these require somewhat complicated apparatus which is tedious to clean between exposures of successive samples. Furthermore there does not appear to exist, at present, any one method which is likely to become accepted by a large number of workers for their varying work. The aim of the present investigation was therefore to devise a method which would have as a primary requirement wide applicability to the analysis of non-ferrous metals, and as a secondary requirement cleanliness of operation. If more than one method were found which fulfilled the above requirements, then, other things being equal, the final order of merit would be determined on the basis of simplicity.

Four Methods Considered

Members of the Panel had limited experience in the operation of one or more of four solution methods, each of which was sufficiently clean and simple to merit consideration and was potentially of wide application. These methods were as follows :

The Cup Method : A small volume of solution is held in a metal or graphite cup electrode, below a pointed counter-electrode. An intermittent discharge is passed between these electrodes.

The Drip-Feed Method : Solution is drip-fed on to the upper of a pair of long graphite electrodes between which an intermittent discharge is passed.

The Powder-Spark Method : The ground residue after evaporation of the solution and ignition is packed into a graphite-cup electrode, below a pointed graphite counter-electrode. A condensed spark discharge is passed between these electrodes.

The Scheibe Method : Short graphite electrodes are impregnated with a drop of solution and oven dried. A condensed-spark discharge is used.

In both cup and drip-feed methods the spark gap may readily be partially enclosed and so ventilated as to avoid the escape of spray into the laboratory atmosphere.

In the experimental programme adopted by the Panel to compare the four methods, it was arranged that each member would report on :

(*a*) the use of methods with which he was familiar in application to analytical problems arising in the course of his work ;

* B.N.F. Report T.M. 79 P. The work described in this article was made available to members of the B.N.F.M.R.A. in a confidential Technical Memorandum issued in August, 1950.

† Now with the British Oxygen Company.

(*b*) the use of a familiar method in application to an unfamiliar analytical problem ;

(*c*) the use of an unfamiliar method in application to an analytical problem of interest in his normal work.

Through the co-operation of members on these lines it became possible to establish a common viewpoint on the comparative cleanliness, simplicity and range of application of the four methods.

It became evident that the Scheibe method had little or no advantage in sensitivity over the less tedious cup method, which is to be preferred on grounds of greater simplicity. The cup method, however, is less sensitive than the powder-spark method, which is therefore essential for applications requiring sensitivity.

The cup method may readily be modified to combine the principle of the drip-feed method, which should lead to rather higher sensitivity, but the Panel has not fully investigated the magnitude of any advantage gained thereby.

Throughout the Panel's work it was clear that the best results with a given method were invariably obtained in the laboratory having the longest experience in the use of that method. This observation emphasises the fact that optimum results should not be expected at once in a laboratory taking up for the first time the use of solution techniques. The reasons why this should be so are hard to find, but are possibly connected with the avoidance of contamination, which becomes easier as familiarity with the manipulation of the method increases.

The Panel is able to recommend two promising solution methods, the cup method and the powder-spark method, which together cover a wide range of applications with success. Of the two, the cup method has been found to be the more readily adopted by a laboratory without experience of the use of either method.

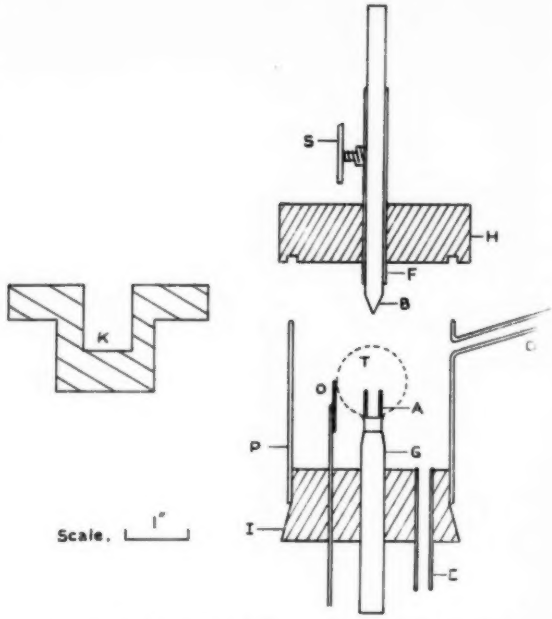
In the following sections will be found a description of these two methods, with examples of the applications for which each has been found suitable. Both methods can be used as micro-methods if desired, in the event that only a small sample is available.

The Cup Method

Principle. A weighed quantity of the alloy to be analysed is dissolved, preferably in nitric acid, to form as concentrated a solution as conveniently practicable. A typical concentration is one of 20 g. of alloy in a litre of a 50% solution of nitric acid with water. Standard solutions are prepared, to cover the composition ranges of interest, from pure metals or from salts of the metallic elements present in the alloy. All the solutions used should be similar in concentration and have the same acid radical.

Approximately 0·1 ml. of solution is transferred to a metal or graphite cup which forms the lower electrode of a pair between which an intermittent discharge is passed. The discharge may be generated by a simple condensed spark unit or, for example, the B.N.F. General Purpose Source Unit. The discharge causes part of the solution to enter the gap as a fine spray. Some solution remains in the cup at the end of the exposure.

Apparatus. A simple form of apparatus which has been found convenient to operate and maintain is shown in Fig. 1. The lower electrode holder *G* is a 4 in. length of $\frac{3}{8}$ in. diameter stainless steel rod, the upper end of



which is drilled and slit to form a spring grip for the short cup electrodes 7 mm. in diameter, which are normally employed. The upper electrode holder *F* is a similar length of $\frac{3}{8}$ in. diameter of stainless steel tube, with its lower end split and sprung to grip 7 mm. diameter rod electrodes. A screw *S* serves to hold electrodes of smaller diameter. The two electrode holders are gripped in a Gramont stand and carry rubber bungs as indicated in the figure. The lower bung *I* is fitted with a drain-tube *E* and an initiating point *O*. This bung supports a glass shield *P* which prevents liquid or corrosive material from falling upon the spectrograph or associated equipment. The shield, a 3 in. length of $2\frac{1}{2}$ in. diameter Pyrex tube, is fitted with a 1 in. length of $\frac{5}{8}$ in. diameter tube *T*, seen in section in the figure, which provides an open path between the discharge and the spectrograph. A small side tube *D* is connected to an exhaust fan, which draws air in through *T* so that spray does not drift out. The upper bung *H* has a concentric groove cut in its lower surface to fit over the upper rim of the tube *P*, so sealing the chamber when the arms of the Gramont stand are racked together.

The lower arm of the stand can be swung out in a horizontal arc against a stop, and, in this position, the apparatus is easily washed out and the electrodes readily changed. Fresh cups are inserted into the spring clip and pushed down by the ebonite jig *K*, so that they are located exactly in the orifice *T* on the axis of the spectrograph. The upper electrode is located with the aid of the same jig or by using the normal projection system.

Electrodes. High-purity copper electrodes have generally been used. The cup *A* is normally a short length of 7 mm. diameter rod, drilled concentrically to provide a hole 5 mm. in diameter and 6 mm. deep. The counter electrode *B* is a similar rod, machined to a conical tip of angle 30°. Both electrodes, when of copper, are cleaned after each exposure by pickling in nitric acid and rinsing well in water. They can be used a number of times before being re-shaped. Alternatively, a copper cup and

graphite counter-electrode has been used, as has also a graphite cup and counter-electrode. For some types of analysis, a cup having a central pillar, the top of which projects about 0·5 mm. above its rim, has been found advantageous in ensuring steady running of the discharge.

Excitation. Spectra are excited either by a simple condensed-spark circuit or by an intermittent arc-discharge such as is provided by the B.N.F. General Purpose Source Unit or by the Kingsbury-McLelland circuit.

Use of Internal Standard. When using a copper cup, it is recommended that an internal standard be added to the solutions to be analysed. Examples are given in the description which follows of results obtained using the cup method.

Examples of Analysis by the Cup Method

I.—Chromium Bronze for Chromium

Chromium is present non-uniformly as undissolved particles in chromium-bronze bearing alloy, and a solution method offers the best way of obtaining a representative sample for spectrographic analysis.

The samples were dissolved in brominated hydrochloric acid (1 g. metal in 8 ml. HCl and 1 ml. Br_2 made up to 100 ml. solution). Standards were made synthetically, using the same reagents, to contain 2·5, 2·0, 1·5, 1·0 and 0·5% chromium.

Nickel sulphate was added in the proportion of 1 g. to 10 ml. of solution to serve as an internal standard.

Excitation : B.N.F. General Purpose Source Unit : 40μF, 4 ohms, 0·03 mH. Solution in copper cup as negative electrode, 4 mm. copper rod as positive electrode ; 4 mm. gap.

Spectrograph : Hilger Medium Quartz (E.498). Condensing lens F.1026. Slit width 0·02 mm.

Plate : Kodak B10.

Exposure : 5/45 sec. (A 60 sec. exposure would be preferable for estimations of less than 1% chromium).

The lines measured were Ni 3548·2, from the added internal standard, and Cr 3578·7.

Standards were photographed in triplicate, with 12 spectra of the 2% chromium standard to indicate the reproducibility. A calibration curve was constructed and the 12 spectra gave a standard deviation of ±0·07%on 2% chromium.

Spectrographic estimates of the chromium content of four samples, analysed by the above technique, are shown in Table I, together with the results of independent chemical analyses of the same materials.

TABLE I.

Sample	% Cr (Spectrographic)	% Cr (Chemical)	
		(a)	(b)
1	1·59	1·37	1·83
2	2·07	2·17	2·17
3	2·09	1·96	2·40
4	0·43	0·51	0·56

II.—Copper Alloys for Lead and Zinc

Lead, like chromium, is present as undissolved particles and these are not always uniformly distributed. In a leaded gunmetal containing approximately 5% lead, 5% tin, 4% zinc and 0·5% nickel, 4 mm. rod electrodes of which were excited by the simple condensed spark, the results for lead gave very poor reproducibility although the results for tin and zinc from the same spectra were entirely satisfactory. This alloy was therefore dissolved in nitric acid and analysed by the cup method, using as standards mixtures of solutions of copper, zinc and lead. In this case, the sample being analysed already contained approximately 0·5% nickel, and an appropriate allowance was made when adding nickel in solution for providing the internal standard. The comparison was made with equal amounts of nickel in the sample and in the standards. A mean of four determinations gave the result 4·74% lead ; chemical analysis gave 4·88%.

The experimental details were :

Excitation : Simple condensed spark : 0·01μF ; 0·06 mH. Solution in copper cup, 4 mm. copper rod with conical tip as counter-electrode ; 4 mm. gap.

Spectrograph : Hilger Medium Quartz (E.498). Slit width 0·02 mm.

Plate : Ilford Ordinary.

Exposure : Spark discharge focussed within the optical system by means of the appropriate lens. Exposures of 30–45 secs. (No pre-spark).

By the use of this procedure, the individual estimates of zinc obtained were 4·33%, 4·33%, 4·75% and 4·13%, as compared with the estimates, by four separate chemical analysts, of 4·40%, 4·10%, 4·02% and 3·95%.

It should be recorded that the spectra were affected by the strength of the acid used, and it is thus important to maintain constancy in this respect.

To assess the accuracy of results obtained by this method, a test was made in which 21 spectra of a solution containing, per litre, 18 g. copper, 1·1 g. zinc and 0·9 g. lead were exposed on each of the two plates together with three synthetic standards ; the standard deviations of the results are shown in Table II.

TABLE II.—STANDARD DEVIATIONS.

	For Zinc	For Lead
Plate 1	±0·20% on 5·4% Zn	±0·18% on 4·4% Pb
Plate 2	±0·28% on 5·6% Zn	±0·19% on 4·4% Pb

III.—Calcium in Aluminium, Magnesium and Zinc.

Calcium in concentrations down to 0·01% is readily detected in these three metals, using a copper cup and counter-electrode and exciting the spectra either by the condensed-spark unit or by the B.N.F. General Purpose Source Unit, set to 20μF, 4 ohms, 0·03 mH. The standard deviation of a single analytical result is about ±10% of the calcium content when this is of the order of 0·1%.

IV.—Boron in Copper and Aluminium.

Boron in copper and tin bronze down to 0·01% and in aluminium down to 0·005% has been determined using the General Purposes Source Unit, with settings as in III above.

V.—Lithium in Copper and Copper Alloys.

Lithium, above a lower limiting concentration of 0·005%, has been estimated in copper, brass, tin-bronze and aluminium bronze. Using an Ilford long-range spectrum plate, the lithium line 6707A is readily measured. The General Purpose Source Unit was set at 100μF, 6 ohms, 0·25 mH.

VI.—CADMIUM IN CADMIUM COPPER.

The use of a graphite cup was successful for the determination of cadmium in cadmium-copper alloys. A copper line was used as a reference line, no separate addition of an internal standard to the solution being found essential.

Limitations of the Metal Cup Method

High-purity aluminium presents a problem when solid electrodes are excited for spectrographic analysis, because the impurities are to some extent segregated at the grain boundaries and the grain size is often so large that the segregated impurities are relatively far apart as compared with other materials. It was therefore a prima facie case for the use of a solution method as dissociated ions in aqueous solution.

A method of high sensitivity and good reproducibility was required, since the impurities are present in rather small quantities, e.g. 0·002% Si, 0·001% Cu, 0·0005% Fe, in the sample available for trial. An arc-like* setting of the General Purpose Source Unit was therefore used, with a 60 sec. exposure, using a Kodak B10 plate. A sample of weight 5 g. was dissolved in 100 ml. of 1 : 1 hydrochloric acid. Some mercuric chloride was used as a solution catalyst. The solution was excited in a copper cup with copper counter-electrode. It was found that there was no consistent difference, in the iron and silicon lines observed, between the solution of the sample and a blank run with distilled water. Furthermore, the variation in individual spectra was so large that it was evident the method as then in use was unsuitable for this determination.

This finding is not surprising when account is taken of the amounts of impurity and the volume of liquid held by the cup; the amounts of the impurities available in the cup are only :

Silicon	..	$1·0 \times 10^{-7}$ g.
Copper	..	$0·5 \times 10^{-7}$ g.
Iron	..	$0·25 \times 10^{-7}$ g.

The limits of detection of other elements, e.g., zinc and lead in a copper solution in the metal cup method using a simple condensed spark were found to be much higher, namely $0·2 \times 10^{-4}$ g. Further, it is not known what proportion of the liquid in the cup becomes sprayed effectively into the discharge but it is likely that the amounts of these elements which actually suffer atomic excitation are even smaller than the figures mentioned above.

The Powder-Spark Method

Principle.—The first stage of the powder-spark method is the same as for the metal cup method, i.e., the sample is dissolved in acid. After this however, it differs in that the solution is evaporated nearly to dryness and ignited to oxide in a silica crucible either in an electric muffle or over a Meker burner. The product is removed and thoroughly ground in an agate mortar for 15–20 minutes, extra care being necessary where insoluble compounds are present (e.g. of tin or silicon).

Graphite rods of ordinary purity are used for electrodes, the lower being drilled to a depth of ¼-in. For light or easily ejected oxides (e.g. Al, Mg, Ca) a $\frac{3}{16}$ in. diameter crater is used, while for heavy oxides (e.g. Cu, Ni, Fe) the diameter is increased to ¼ in. The crater is loosely filled with oxide and levelled off. An 80° pointed graphite rod is used for the upper electrode and is mounted concentrically 3 mm. above the rim of the crater.

In the methods described below the Hilger spark circuit set to 10 kV, 0·005 μfd and 0·13 mH is used for excitation and the exposure depends on the matrix. Thus, with a slit width of 0·025 mm. for an E.498 spectrograph times of 20 secs. and 60 secs. have been found satisfactory for the estimation of added constituents in aluminium and copper alloys respectively, and these exposures are doubled for the estimation of impurities. It has been customary to make exposures in duplicate, with fresh craters, on Kodak B10 plates, rejecting any test in which the crater empties completely. The interpretation may be either visual or microphotometric depending on the accuracy required. As in the metal cup method, standards are prepared by making additions of the element to be estimated to a blank. For the latter pure metals may be used, e.g., electrolytic copper and zinc in the proportions 70 : 30 would be equivalent to brass. For the additions the metal or its oxide is dissolved, diluted, and the necessary aliquots are added to the solutions of the synthetic matrix, further stages being completed simultaneously with the unknown samples.

Where insoluble compounds only are available for the preparation of standards, an amount equivalent to the highest standard required, preferably not less than 1%, is added to a known weight of matrix oxide and ground. A portion is diluted with more of the matrix oxide, the process being repeated until sufficient standards to cover the range required have been made.

The main advantage of the Powder-Spark Method as compared with the Metal Cup Method is that a much greater weight of material is available for the analysis even using only one filling of the cavity in the electrode. The reason for this is, of course, the absence of water, obviating the need to keep the concentration of dissolved material below its solubility limit. Thus the graphite cup holds more than 0·3 g. of powdered solid copper oxide whereas the weight of copper which would be in solution in the metal cup at one filling would be only 0·0018 g. The method therefore has very good sensitivity. Reproducibility is as good as in the other method. In addition, no special apparatus is involved, while the Hilger spark circuit used for excitation is available in most laboratories. It is applicable to materials partially or wholly insoluble, either as samples or as chemicals to be used for preparation of standards. In addition, the influence of one constituent on others is lower than when metallic electrodes are used.

Examples of Analysis by the Powder-Spark Method

I.—ALUMINIUM ALLOYS FOR IRON, MAGNESIUM, MANGANESE AND SILICON.

These elements have been estimated in the range 0·2–1·5% by the general method described. Approximately 1 g. of drillings was dissolved in 25% nitric acid, using resistance-type glassware. When action had ceased, solutions were evaporated to the viscous stage before transferring them to silica crucibles. Heating was continued, controlling the tendency of the material to climb over the edge by directing a Bunsen flame in the opposing direction. Ignition was completed in an electric muffle at 800° C. Standards were prepared simultaneously with the unknowns by converting chemically analysed samples to oxide. Alternatively,

* C = 120 microfarad. L = 0·25 millihenry. R = 6 ohms.

synthetic standards were made from pure materials, dissolving the requisite amounts and completing subsequent stages as for the analysis samples. Craters of $\frac{3}{16}$ in. diameter were used together with other conditions detailed above.

Microphotometric readings were made on the following lines: Fe 3047, Mg 2780, Mn 2610, Si 2881 and Al 3066 for comparison. These lines are free from interference arising from impurities or constituents present in current specifications. For interpretation, density differences were plotted against logarithm of percentage. A standard deviation of 5–6% of the amount being estimated was obtained when taking the average of duplicate determination.

II.—High-Purity Aluminium.

This analysis could be successfully carried out only by exercising the greatest care at every stage of the method. The following modifications to the general method were introduced.

Hydrochloric acid was used for dissolution in platinum vessels. In order to avoid possible loss of volatile chlorides on heating, excess ammonia was added in order to precipitate the mixed hydroxides. Evaporation and ignition were then completed normally. No trouble was experienced with silica contamination from grinding in an agate mortar. For electrodes, the super-purity type graphite rods were proved to be desirable. The excitation conditions quoted earlier were found satisfactory just to detect the quantities of impurities present in the sample tested by the cup method, i.e., 0·002% Si, 0·001% Cu and 0·005% Fe, while in synthetic standards 0·001% Mg and Mn were visible.

III.—Aluminium Alloys for Beryllium.

The powder-spark method has been used successfully for the estimation of beryllium. In one sample of drillings beryllium was reported as 0·0025%. A chemical determination on the same sample gave as result "less than 0·01%."

IV.—Chromium Bronze for Nickel.

With the arc technique and solid electrodes, the nickel lines in the spectrum from a chromium bronze may be suppressed by the chromium. However, using the powder-spark method, nickel has been determined within the range 0·05% to 0·20%, the graphs being identical with those for chromium-free copper.

V.—Copper Alloys for Boron.

Boron in a copper-manganese-nickel bronze has been estimated within the range 0·002% to 0·05%.

VI.—Copper Alloys for Aluminium.

Aluminium in a tin-bronze has been estimated within the range 0·002% to 0·02%.

Limitations of the Powder-Spark Method

The main disadvantage of this method is that the time for sample preparation, including evaporation and grinding, is considerably greater than in the cup method. These operations also introduce a risk of contamination. It is necessary that samples and standards should be present as the same radical, preferably as oxides freshly prepared. Some experience may be necessary to acquire skill to treat different samples in the same way. If constant conditions are not maintained during preparation inaccurate results will be obtained. An example of this occurred in the estimation of 5% zinc and tin in a bronze where the method of igniting the oxide influenced intensity ratios.

During excitation, excess powder falls on the bench and on spectrographic equipment in the vicinity, and this could be a cause of contamination of samples subsequently analysed.

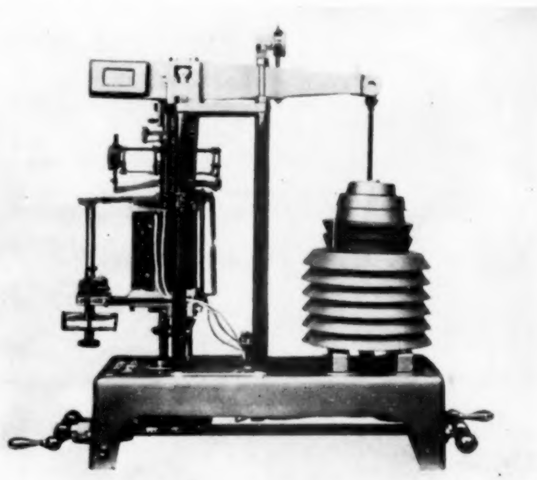
The powder-spark method was found to be unsuccessful for the estimation of added constituents in magnesium alloys, although 0·002% iron, present as an impurity, could be estimated satisfactorily.

Conclusion

The aim of the report has been to show the Panel's reasons for selecting the cup and powder-spark techniques as best combining, for the purposes of metallurgical analysis, the features of simplicity, cleanliness and range of application. It is unfortunate that no single method has been found which embodies all the requirements so well as to make it universally useful. Such a method may yet be developed, but, in the meantime, members of the Panel felt that their experiences in the application of solution techniques would be of general interest. The description of principles, with examples of their application, set out in the report will, it is hoped, help those who have analytical problems for which a solution method appears appropriate, to develop useful procedures with a minimum of effort.

Creep Testing Machine at South Bank

One of the exhibits at the South Bank site is a Model T47 High Temperature Miniature Creep Testing Machine made by Saml. Denison & Son, Ltd., Leeds. This



machine, which is shown here complete with electric furnace, temperature regulator and special extensometer, is based on a design developed by Mr. G. T. Harris, M.A., F.Inst.P., of the Research Department of William Jessop & Sons, Ltd., Sheffield. Suitable for use up to 900° C., it is of the vertical type, self-contained and arranged for bench mounting. The straining or setting gear is of the screw and bevel type operated by swapes at each end of the machine, and the specimen holders, of heat and creep resisting material, are connected to steelyard and setting screw by means of universal joints.

The Manufacture of Sintered Alumina Ware

By R. Scott, B.Sc., A.Inst.P.*

The techniques used in making sintered alumina, both for laboratory ware and other purposes, often cause difficulty to those with no previous experience in the field. On the other hand, various research laboratories have been in the habit of manufacturing their own alumina bodies for some years past. These laboratories recently prepared papers on their techniques for the Sintered Oxides Sub-Committee (Inter-Service Metallurgical Research Council, Admiralty and Ministry of Supply), and the information gathered is now released in the hope that it may be useful to those desiring guidance. Most emphasis is placed on the slipcasting method in this series of papers published by kind permission of the Chief of the Royal Naval Scientific Service, and the Chief Scientist, Ministry of Supply. This is the second paper of the series.

SINTERED alumina ware has been made in Germany since the early 1930's under the trade name of "Sinterkorund" and in England during the past 10 years or so. Descriptions of the detailed technique of manufacture are, however, very few and vague and the following brief notes are an account of the development of a satisfactory method of making small articles of pure alumina, mainly for use in our own laboratories. From the start we were guided by the information contained in F.I.A.T. reports of wartime German practice, and our experience so far has been confined to the slip-casting method of manufacture.

Raw Material

The raw material was calcined alumina as used for the electrolytic production of aluminium metal. This material is in the form of a fine powder, a sieve analysis giving the following grading :—

+ 120	B.S.S.	1·5%
− 120 + 150	,,	3·5%
− 150 + 200	,,	15·0%
− 200	,,	80·0%

No chemical analysis was carried out but references in the literature to similar material from the same source indicate that it contains not less than 99% Al_2O_3. It was calcined at high temperature and so, presumably, consists of the α modification. This powder was still further reduced in size by milling.

Grinding

The milling was carried out in a steel ball mill of 10 in. internal diameter, a charge consisting of 22 Kg. balls, 2·2 Kg. alumina and 2 litres of water. The steel balls varied in diameter from ¾ in. to ¼ in. Grinding was continued for 16 hours at 63 r.p.m., after which microscopical examination of a sample showed that all the particles were less than 20 μ in diameter and the great majority less than 5 μ. The charge was then transferred to a large stoneware jar and 600 ml. of concentrated hydrochloric acid added slowly. Meanwhile the suspension was heated to about 95° C. by passing in steam for 1 hour. This treatment results in the rapid and complete solution of the iron contamination and is considered to confer a higher green strength to the ware after casting. The slip was allowed to cool and settle overnight, after which the supernatant liquid was siphoned off. A large quantity of water was then added, the mixture stirred with a wooden stick and again allowed to settle overnight after which the clear liquid was again siphoned off. This washing process was repeated until the solid matter remaining was quite white (the material immediately after grinding being a dirty grey colour). The water content of the slip was finally adjusted to give a specific gravity of 2 (i.e. 70% solids) and the acid content adjusted to 1% by weight. Immediately prior to casting the slip was de-aerated for half an hour at a pressure of 1–2 cm. mercury; omission of the de-aeration process invariably resulted in the appearance of numerous air-bubbles and pin holes in the cast ware.

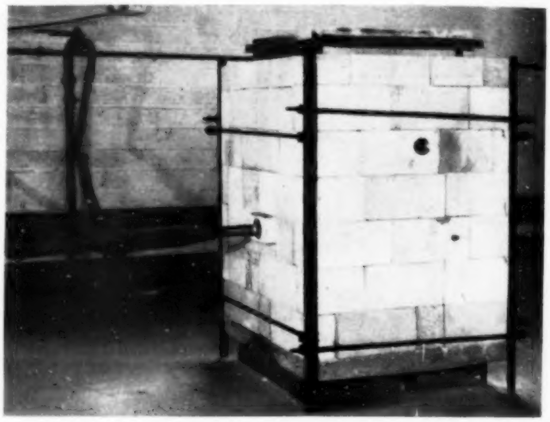


Fig. 1.—General view of sintering furnace.

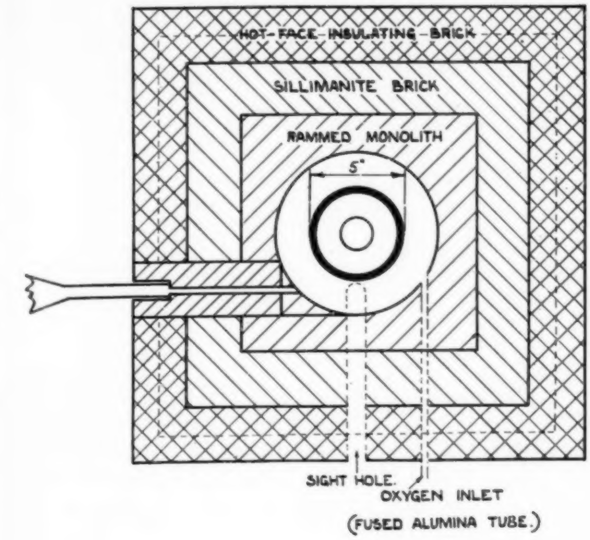
Casting

Casting was carried out in ordinary plaster moulds made with equal parts by weight of plaster and water. Small crucibles, etc., were made by single or open casting, this method giving the ware a very smooth inside surface. Slip made as described above casts very rapidly, 5–10 seconds being sufficient for a wall thickness of 1–2 mm. Such thin-walled articles can be safely removed from the mould after about an hour, and possess sufficient green strength to be handled safely with a little care. They can be dried rapidly but articles with wall-thicknesses greater than 2 mm. must be left in the mould overnight and dried very slowly ; otherwise very fine hair cracks are formed, which only become apparent after firing, when they open up considerably. The drying shrinkage is very small and may occasionally be so small as to present difficulties in extracting the ware from the mould. This difficulty was, however, invariably overcome by making the slip slightly more acid.

Firing

Ryschkewitsch has shown that pure alumina cannot be completely sintered at temperature below 1,770° C., regardless of the duration of firing. This was borne out

* Communication from the British Ceramic Research Association, Stoke-on-Trent.



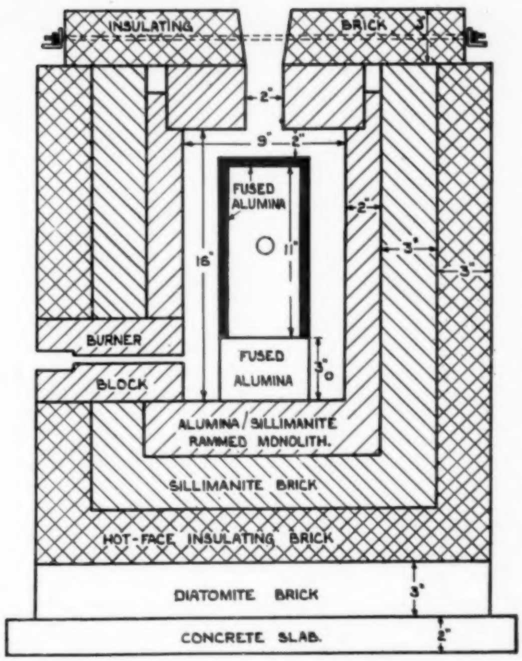


Fig. 2.—Drawing of sintering furnace showing plan view (above) and elevation (right).

by our own experience ; ware fired to 1,600° C. for 2 hours was very strong and had a good ring, but still had a porosity of at least 10%. This fact necessitated the construction of a special furnace to reach a temperature of at least 1,800° C. (see Figs. 1 and 2). The inner zone is cylindrical and a single tangential " burner " of our own design and manufacture is used. A mix consisting of 50% fused alumina, 40% sillimanite, and 10% ball clay rammed with 5% of water, is used for the rammed monolith inner lining. The inside diameter of the monolith is 9 in. and the height 16 in. A square-section outside enables standard 9 $\times$ 4½ $\times$ 3 in. brick to be used with a minimum of cutting for the 3 in. sillimanite-brick and 3 in. high-temperature insulating-brick layers with which it is surrounded. A jointing cement consisting of 90% fine sillimanite and 10% china clay was used for the sillimanite-brick layer, and the whole assembly held together by angle iron and spring loaded tie-rods. The furnace is charged from the top, the lid being 12 in. in diameter, 2½ in. thick, with a central hole 2 in. in diameter for the escape of burnt gas, and is made from the same mix as the inner lining. A second 18 in. square lid is made up of 8 standard 9 $\times$ 4½ $\times$ 3 in. high-temperature insulating bricks, held together by angle iron and tie rods, and has a central hole which tapers to 2½ in. diameter at the top. The articles to be fired are carefully packed in fused alumina in a central alumina saggar 5 in. in diameter, the combustion chamber being the annular space, 2 in. wide, between the inner lining and the saggar. Owing to its geometrical configuration, this space presents a large surface in relation to its volume, so that surface combustion plays an important role in the operation of the furnace. Furthermore the velocity of the burnt gases is high, which leads to a high rate of heat transfer and consequently great uniformity of temperature. The " burner " consists essentially of two concentric tubes with air under pressure passing through the inner one, which terminates in an orifice of diameter $\frac{11}{32}$ in. The action of this burner is similar to that of the familiar diffusion pump, the jet of air issuing from the orifice producing a partial vacuum in the gas line between the gas valve and the burner. A water manometer placed here shows a partial vacuum of from 0–12 in. depending on the settings of the air and gas valves. The burner thus acts as a gas booster giving an effective gas pressure up to about 18 in. of water. This arrangement is not a burner in the usually accepted sense ; it merely serves to introduce into the furnace an adequate supply of gas and air. Mixing and combustion take place in the annular space so that the furnace itself is the burner. The existence of the partial vacuum in the gas line also enables the gas to be pre-mixed with a certain amount of air merely by opening to the atmosphere a screw-operated needle valve situated between the gas valve and the burner. By proper manipulation of the three valves the furnace can be heated to 1,650° C. in 2½ hours if necessary, with complete control of the furnace atmosphere. For higher temperatures the gas supply is increased slightly and oxygen introduced through the tube which opens into the furnace opposite the gas-air entrance. This tube is a short length of fused alumina thermocouple sheath of internal diameter ¼ in. A temperature of 1,800° C. has been reached and maintained for half an hour with a consumption of only 50 cu. ft. of oxygen. Temperatures are noted by means of an optical pyrometer through the 1 in. diameter hole half way up the inner zone. As the inner end of this hole consists of a closed-ended sintered alumina tube in contact with the inner saggar, black-body conditions are closely approximated and the pyrometer readings are not subject to error due to sighting through flame.

The firing schedule depends on the particular ware being fired ; thick-walled articles should be fired more slowly than thin-walled ones. Up to 1,300° C. very little firing shrinkage occurs but thereafter the shrinkage is rapid so that the rate of heating should be reduced above

this temperature. Provided the ware is quite dry when put into the furnace the temperature may be safely raised to 1,300° C. in 2 hours. From 1,300° C. upwards a rate of 200° C. per hour is safe for crucibles and tubes having a wall thickness up to 2 mm. The duration of firing at the maximum temperature does not appear to be critical; half an hour at 1,800° C. has produced crucibles which were translucent and apparently well vitrified. The furnace atmosphere should be oxidising throughout as a reducing atmosphere has been reported as detrimentally affecting the strength of the fired articles.

Acknowledgment

This paper is published by kind permission of Dr. A. T. Green, O.B.E., Director of Research, the British Ceramic Research Association.

The Study of Dusts in Industrial Atmospheres

V.—The Determination of Mass Concentration by the Volatile Filter Method

By P. F. Holt, B.Sc., Ph.D., D.I.C., F.R.I.C.

University of Reading.

The standard method for mass concentration measurement uses a volatile filter material such as naphthalene. Following a description of this method, the author discusses the advantages and disadvantages of the particle size count and the mass concentration determination.

THE very extensive study of the atmospheres of South Wales coal mines, which was commenced in 1937 by the Medical Research Council and extended into the early years of the war, required the measurement of the mass concentration of dust at a large number of points in many different collieries. The hundreds of samples necessary to obtain values of statistical significance for the comparison of conditions between one colliery and another could not be obtained conveniently by a method which needed compressed air lines at every sampling point. The alternative method of sampling which was developed is one of the simplest and most convenient procedures available, yet it enables mass concentration to be measured with a high degree of accuracy. It has become the standard method for mass concentration measurement.

Fig. 1.—Measurement of the dust concentration at a colliery loading point, using a naphthalene filter and a hand pump.

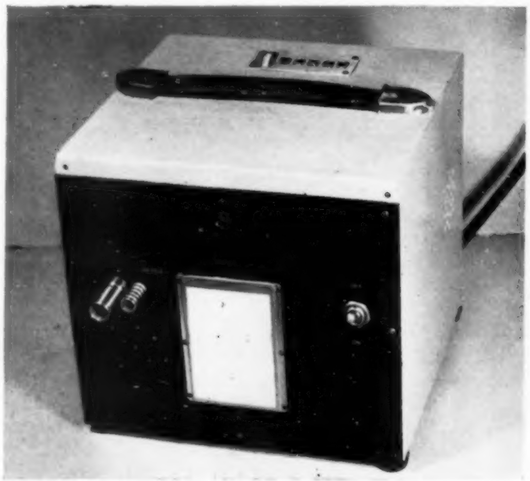


Fig. 2.—Electrical dust sampling apparatus which utilises the naphthalene filter.

The Naphthalene Filter

Filtration is effected by drawing a measured volume of air through a pad of naphthalene compressed on to a perforated disc which is held inside a short length of metal tube. The dust which is retained by the naphthalene is transferred with the pad to a small, weighed platinum or aluminium dish. Removal of the naphthalene is then effected by heating the dish to a temperature slightly below 80° C. when it sublimes away leaving an uncontaminated dust sample. A second weighing enables the mass of the dust to be determined. Weighings are carried out on a micro-balance thus enabling samples as small as 20–30 micrograms to be accurately estimated.

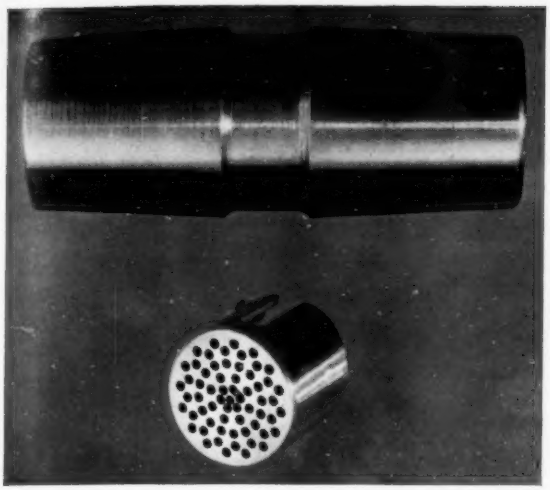


Fig. 3.—Latest design of naphthalene filter holder in stainless steel.

Naphthalene filter samples may be taken by means of a hand pump of known stroke volume (ordinarily 100 ml.) and this method is usually satisfactory in collieries, where dust concentration is high. Fig. 1 shows samples being taken by this means at a colliery loading point. The volume sampled must contain not less than about 30 micrograms of dust. Recently an electrically-driven sampling pump has been designed (Fig. 2) which, sampling at a rate of 2,000 ml. per minute, can be left running without attention. The volume of sampled air is either measured with a meter or is calculated from the number of strokes made by the pump.

Naphthalene is appreciably volatile at ordinary temperatures and the filter pad begins to disintegrate if air volumes in excess of about 40 litres are sampled. By using a less volatile filter base it is possible to take samples from almost any air volume; the sampling time may be made to coincide with a working shift, and may thus give a value for the average dustiness during that period.

Since its introduction in 1938, the design of the naphthalene filter holder has been improved; a later form is shown in Fig. 3. The outer case is in the form of a double cone and the filter can be plugged directly into a socket in the sampling pump so that connection is made without using rubber tubing. A standard taper is used, enabling connection to be made with Quickfit laboratory apparatus if required. The perforated disc on to which the naphthalene is compressed, and which is normally inside the holder, is also shown in the illustration. The length of the holder is 4 cm. and the diameter of the filter pad is 1·1 cm.

So that naphthalene filters shall give a reasonably uniform sampling rate, a standard procedure is adopted for preparing them. Naphthalene normally crystallises in large, thin plates and filters prepared directly from this material are very highly resistant to air flow. The naphthalene is first melted, therefore, by rapidly heating to about 100° C., then it is quickly cooled by pouring the liquid into a tray made from aluminium foil. The napthalene sets into a solid block which is easily removed to an agate mortar. It is broken up by tapping with the pestle but without grinding. It is then sieved through a 20-mesh stainless steel gauze, coarser particles being returned to the mortar for further treatment. In this way a granular powder is obtained.

The naphthalene pads are formed with compression tools of the type shown in Fig. 4. The filter holder is held in the stand and the space above the perforated disc is loosely filled with the prepared naphthalene. A standard pressure is then applied with the compression tool, which contains a calibrated spring. The filters are quite stable to shock; they should be used within seven to ten days, however, since the high vapour pressure of the naphthalene inevitably means that the larger particles grow at the expense of the smaller and the pore size steadily increases. This does not apply when other less volatile filter bases are used; filters can then be stored for any length of time.

The removal of the naphthalene from the filter pad is effected by sublimation. This requires some form of apparatus in which the pad in its metal dish can be heated to a temperature which is just below the melting point of naphthalene and careful temperature control is necessary. An electrically heated copper block on which the dishes may be stood has proved satisfactory, but a glass apparatus of the type shown in Fig. 5 is more useful. The dishes containing the samples are placed on a copper block in a central glass chamber which is jacketed. The chamber is heated by the vapour of a liquid which boils at the required temperature; ethyl acetate, which boils at 77° C. is suitable for the sublimation of naphthalene. A current of filtered air is drawn slowly through the apparatus, entering through a fine capillary, and it is thus possible to run the apparatus under reduced pressure, thereby facilitating sublimation.

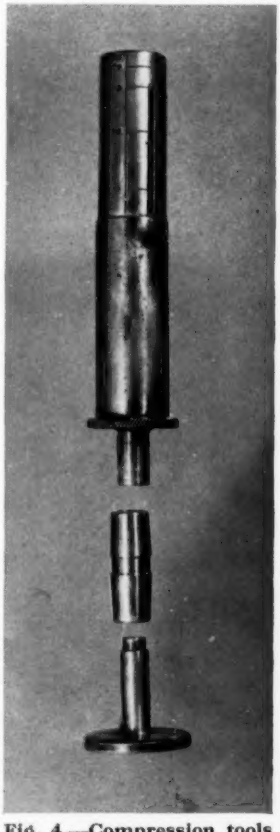


Fig. 4.—Compression tools for preparing naphthalene filters.

Nature of the Dust

Although the main use of the naphthalene filter is to determine the mass concentration of dusts, it is often possible to obtain information about the nature of the dust by applying microchemical methods. It is always possible to estimate volatile material in the dust sample by igniting the dust and re-weighing. If more than five milligrams of dust are available, analysis for all the major constituents can usually be effected by using micro-gravimetric methods for silica, aluminium, calcium and magnesium, and colorimetric methods for constituents present in smaller amounts. Even on very small samples, partial analysis

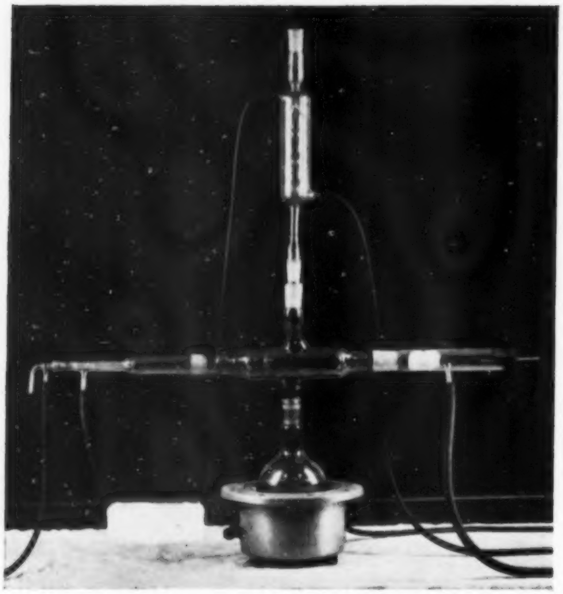


Fig. 5.—Sublimation for the removal of the filter base at a controlled temperature.

is possible by the adoption of colorimetric methods. For more extensive analytical investigations it is preferable to obtain larger samples whenever possible and these are most readily collected by the salicylic acid filter.

The method has also been used for sampling organic dusts which are coloured or which can be made to react with suitable reagents to give a coloured solution. The dust formed when aromatic nitro compounds are handled has been investigated by this means. If the compound is soluble in benzene to give a coloured solution, it can be estimated simply by dissolving the naphthalene pad and dust together in this solvent and determining the concentration of the nitro compound by measuring the intensity of the coloured solution.

Particle Size Distribution v. Mass Concentration

The apparatus which has been described in this and previous articles is intended to measure dust concentrations either as the weight of dust or as the number of particles in a stated volume of air. It may be useful here to summarise the advantages and disadvantages of each method. So far as the physiological action of dust is concerned, it is almost certain that its activity is a function of its surface area although the exact mechanism of the formation of tissue damage is still uncertain. It is impossible to relate its other undesirable properties, such as its abrasive action on mechanical parts, either to surface, to mass or to particle size. But not all the particles in an air-borne dust cloud of a potentially dangerous dust can cause damage to lung tissue. Very small particles (i.e., below about 0·5 micron) are not retained by the lung but behave like gas molecules and are exhaled. Large particles, on the other hand, do not reach the terminal air sacs of the lung; they are thrown out on to the walls of the upper respiratory tracts. For this reason a true picture of the potential danger of a dust cannot be obtained from a total count of all the particles in the atmosphere; it is preferable to count only particles in the size range 0·5 to 5 microns. For a complete characterisation, a differential count is required and the number of particles in each size range must be stated, but a differential count is really of value only if an accurate sampling apparatus, such as the thermal precipitator, is used. If accurate count and size distribution figures are available, then it is possible to calculate an approximate mass concentration value from these data.

The mass concentration values can never give complete information about a dust but, provided precautions are taken to exclude very large particles from the samples, the figures are of much greater value in assessing the potential danger of a dust cloud than would at first seem apparent because the weight is mainly due to dust which is potentially dangerous, the weight of the very small particles which are not retained by the lung being negligible. Moreover the modern procedure for the measurement of mass concentration is extremely simple, both as regards the collection of samples in the field and their evaluation in the laboratory. Perhaps the most important advantage of this method over counting methods lies in the possibility of obtaining average concentration figures by collecting samples over several hours. To do this accurately by a counting method requires the evaluation of a large number of samples by microscopic examination, a procedure which is both tedious and time-consuming.

For dust control, when comparative rather than absolute values of the dust concentration are needed, it would seem that there is little to choose between mass concentration figures and particle counts, provided that sampling conditions are kept standard. It would be a considerable advantage if one standard procedure were adopted, at least throughout the metal industries, so that values obtained at one works would be comparable with those obtained elsewhere. It is probably true that the Owen's jet apparatus is most widely used for obtaining comparative counts and the naphthalene filter for measuring mass concentrations in the steel industry. Lawrie[1] developed a rapid method of evaluating samples taken with the jet sampler which has been further developed by the British Iron and Steel Research Association. Photomicrographs are compared with a set of standards when, without counting, the sample can be readily relegated to a particular concentration range. The agreement with accurate counts is amply close to justify the use of the method in control work. Automatic dust monitoring is also being developed in the industry and is sure to play an increasing part in tackling the problem of dust control. This type of apparatus will be discussed later.

1 Lawrie, W. B. "A Rapid Method of Dust Estimation in Iron and Steel Foundries." Soc. Chem. Ind. Conference. September, 1948.

Liaison Shares of Tube Investments and Stewarts and Lloyds

TUBE INVESTMENTS, LTD. announce that the consideration payable to Stewarts & Lloyds, Ltd. for the cancellation of the special rights attaching to the liaison shares held by Tube Investments, Ltd. and Stewarts & Lloyds, Ltd. has been agreed at £650,000. Shareholders will be notified shortly of the arrangements for carrying these terms into effect, which will result in the 500 liaison shares in Tube Investments, Ltd. being converted into 500 ordinary shares as from February 14th last.